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The Goniatite Zones of the Namurian

By R. G. S. Hudson

RECENT work, both published and unpublished, has considerably increased our knowledge of the goniatite succession in the Namurian of western Europe and the various zones and subzones can now be defined more precisely than hitherto. The major divisions of the Namurian of most value are the former "genus zones" each now raised to the status of an age. Names for these divisions were instituted by Bisat (1928), and were redefined by Hudson and Cotton (1943). The various zones and subzones into which the stages are divided are shown on page 2. The zones differ little from those of previous authors: an attempt has been made to give them equal value and, where possible, the zonal indices in any one stage are of the same genus, thus helping to avoid the confusion caused by the choice as zonal indices of forms of different faunal phase. Neither zonal or subzonal indices are constant in their range in their respective divisions—many of them are confined to a faunal band within the subzone, a few extend into a neighbouring division. The following brief notes are based mainly on the faunal succession of the north of England. The published details of the goniatite faunas in Belgium, Holland, Westphalia, and to a certain extent in Silesia show that the succession there is the same. Comparable forms occur elsewhere as in the Pyrenees, North Africa, Novaya Zemlya, Donetz Basin, Indo-China, Siberia, and U.S.A. The boundaries of the Namurian are those decided on at the Heerlen Congress on Carboniferous Stratigraphy (Jongmans and Gothan, 1937).

PENDLEIAN (Hudson and Cotton 1943)

The fauna of this stage is perhaps the least known of all in the Namurian. *Cravenoceras* and *Eumorphoceras* are the common genera, but are often mutually exclusive. I once collected several hundred specimens of *E. pseudobilingue* from bullions in Cow Close Sike, Malham, but not one specimen of *Cravenoceras*. In the same way the *C. malhamense* beds contain few, if any, specimens of *Eumorphoceras*. The usual zonal indices for this stage (see Bisat, 1928, pl. vi; Moore, 1936, p. 168) are:

C. malhamense.
E. pseudobilingue.
C. leion.

The following abbreviations of generic names are used throughout this paper: *A.*, *Agastrioceras*; *An.*, *Anthracoceras*; *C.*, *Cravenoceras*; *Ct.*, *Cravenoceratoides*; *D.*, *Dimorphoceras*; *E.*, *Eumorphoceras*; *G.*, *Gastrioceras*; *H.*, *Homoceras*; *Ht.*, *Homoceratoides*; *N.*, *Nuculoceras*; *Nd.*, *Neodimorphoceras*; *R.*, *Reticuloceras*; *S.*, *Sagittoceras*.

Subdivisions of the Namurian

Stages	*Zones*	*Subzones.*
Yeadonian (Lower *Gastrioceras* Age, G_1)	*G. cumbriense*	*G. cumbriense*
		G. aff. *crenulatum*
	G. rurae	*G. rurae*
		G. cancellatum
Marsdenian (Upper *Reticuloceras* Age, R_2)	*R. superbilingue*	*R. superbilingue*
		R. metabilingue
	R. bilingue	*R. bilingue* late form
		R. bilingue
	R. gracile	*R. gracile*
		R. aff. *gracile*
Kinderscoutian (Lower *Reticuloceras* Age, R_1)	*R. reticulatum*	*R. co-reticulatum*
		R. reticulatum
	R. eoreticulatum	*R. nodosum*
		R. dubium
	R. inconstans	*R. todmordenense*
		R. inconstans
Sabdenian (*Homoceras* Age, H)	*H. eostriolatum*	*H. eostriolatum*
		H. undulatum
		H. smithi
	H. beyrichianum	*H. beyrichianum*
		H. subglobosum
Arnsbergian (Upper *Eumorphoceras* Age, E_2)	*N. nuculum*	*N. nuculum*
		Ct. nititoides
	Ct. nitidus	*Ct. stellarum*
		Ct. nitidus
		Ct. bisati
	E. bisulcatum s.s.	(not divided)
Pendleian (Lower *Eumorphoceras* Age, E_1)	*Eumorphoceras* sp.	*C. cowlingense*
		C. malhamense
	E. pseudobilingue	(not divided)
	E. tornquisti	(not divided)

It is also possible to use various forms of *Eumorphoceras* to divide the fauna of the stage though not all of them have been given specific identity.

The lowest fauna is that characterized by *E. tornquisti* and *C. leion* (Parkinson, 1936, p. 318; Hudson and Cotton, 1943, p. 169; Hudson and Mitchell, 1937, p. 26; Black, 1940, p. 317; Moore, 1936, p. 178; and 1941, p. 253; Gill, 1940, p. 262. In most of these papers *E. tornquisti* is recorded as *S. coronula* or *E. pseudobilingue* early form).

The main fauna of the stage is that of the middle zone, characterized by *E. pseudobilingue*. It is probable that this zone could be divided up into subzones by varying forms of this species (Bisat, 1933, pl. 30; Moore, 1936, p. 178; Parkinson, 1936, p. 319).

The zone of *Eumorphoceras* sp. can be divided into an upper subzone characterized by the index form and *C. cowlingense* group, and a lower one with *C. malhamense* and *Nd. scaliger* (or *Nd. hawkinsi*). The lower fauna has been recognized from many areas (as Moore, 1936, p. 179; Parkinson, 1936, p. 319); that of the upper subzone, however, has not been described in detail with the result that there is no surety of faunal correlation at this level, and the allocation to this subzone of the various beds mentioned below is based as much on their stratigraphical position as on their faunal content. The fauna of the subzone occurred in the boring at Alport about 60 feet below a band with a *E. bisulcatum* (E_2a) subzonal fauna and about 70 feet above a band with a *C. malhamense* subzonal fauna (Hudson and Cotton, 1943, p. 166). It included a *Eumorphoceras* possibly intermediate between *E. bisulcatum* and *E. pseudobilingue*, a *Cravenoceras* which as far as could be determined from crushed specimens was *C. cowlingense* and a fairly characteristic lamellibranch fauna. The fauna is similar to that of a band exposed near Warley Wise, Lothersdale (Bray, 1927, p. 53), and at Edge and other places in Airedale. (Stephens *et al.*, 1942, p. 348), which contains a *Eumorphoceras* which was recorded by Bisat (1924, p. 57) as *E. bisulcatum* or *pseudobilingue* though later authors named it *E. bisulcatum*. The band is often taken as the base of the Arnsbergian (E_2) mainly, I think, because it is divided from the *C. malhamense* beds by 1,500 feet or more of apparently unfossiliferous grits and shales, the Skipton Moor Grits. Since, however, its fauna is, in my opinion, more nearly allied to that of the Pendleian than that of the Arnsbergian it is here, as in Hudson and Cotton (1943, p. 166), included in the former. It is probable that the horizon of the Warley Wise and Edge marine band is that of *C. cowlingense* which was founded on uncrushed specimens not collected in place. This species has also been recognized in north-west Yorkshire in the Mirk Fell beds in the Upper Yoredales (Hudson, 1941) and, further south, from a limestone immediately above the Grassington Grit of Greenhow where it is associated with a *Eumorphoceras* for which a new species is being erected (Dunham and Stubblefield, 1944): numerous specimens have also been found not in place in upper Nidderdale suggesting that they occur above the Grassington Grit of that area. If as is likely the horizons at which these forms are found are the same as that of the Warley Wise and Edge marine band their occurrence links the Pendleian of both Millstone Grit and Yoredale facies.

Various species of *Dimorphoceras* are apparently characteristic of the lower zones of this stage (Moore, 1939, p. 127). The stage has been recognized, though not subdivided, in Belgium (Dorlodot and Delépine, 1930), in Westphalia (Schmidt, 1933), and doubtfully in Silesia (Wirth, 1931; Patteisky, 1933). The species of *Cravenoceras* from Nevada (Miller and Furnish, 1940, p. 373) are of Chester age and possibly belong to this stage.

Arnsbergian (Hudson and Cotton 1943)

The distinctiveness of the three faunas which serve as a basis for the division of this stage into three zones and the succession of faunas within the zones are now fairly well established. *E. bisulcatum s. l.* occurs

throughout the stage and would be a better basis for its subdivision except that it is only common in the lower parts of the stage. The three faunas are recognized in Westphalia (Schmidt, 1933) though they are not given the same status nor have they the same limits. In Silesia the stage is characterized by *Anthracoceras* and species of *Cravenoceras* such as *C. roemeri* and *C. macrocephalum*, closely allied to British forms: *E. bisulcatum* is also occasionally found (Swarzbach, 1937).

Various species of *Anthracoceras* occur throughout the stage (Bisat, 1934), but are so difficult to distinguish in shale specimens that their zonal significance has not been determined.

E. bisulcatum s.s. zone.—Where fossiliferous, this zone usually contains abundant specimens of the index form but, unfortunately, fossiliferous beds are only known to be exposed in the Pennines in Edale (Hudson and Cotton, MS.) and in Wharfedale near Otley and Leathley (Bisat, 1924, p. 52; Stephens *et al.*, 1942, p. 349; Hudson, 1944). A faunal band in this zone was also recorded from the Alport bore (Hudson and Cotton, 1943, p. 163).

Ct. nitidus zone.—The faunas of the *Ct. bisati*, *Ct. nitidus*, and *Ct. stellarum* subzones have been known for some time, but their order has only been recently established (Hudson, 1944). The zone is best exposed in Edale (Jackson, 1927, p. 27), though there are also several sections giving a succession of faunas in the Lancaster Fells and the Knaresborough Forest and Rombalds Moor areas (Hudson, 1944). The *Ct. bisati* subzone contains a lower faunal band with *C. subplicatum* and an upper one with *Ct. bisati*[1]—uncrushed specimens of this species from the mid-Pennines are referred to as *Ct.* aff. *edalensis* (Bisat, 1932, p. 31; Stephens *et al.*, 1942, p. 349). The *Ct. nitidus* subzone also contains two faunas, a lower one with *C. holmesi* and an upper one with *Ct. nitidus*, the relation of the two faunas being known from exposures in Greenholes Beck in the Lancaster Fells and in the R. Noe in Edale (Hudson, 1944). *E. bisulcatum* var. *varicata* is a common form in the *Ct. nitidus* zone.

Faunas of the *Ct. bisati* and the *Ct. nitidus* subzones occur, in part, in the shales exposed in Coppice Beck near Harrogate, in the R. Noe near Edale (Jackson, 1927) and in the Alport boring, thus making it possible to fix the relative position of the two subzones.

The *Ct. stellarum* fauna is only abundant near the base of the subzone where it occurs in a band of wide distribution and of constant lithology and faunal content. Its relation to the subzonal faunas above and below it can best be demonstrated in a section in the R. Noe at Edale described by Jackson (1927, p. 27) and in sections near the junction of the Noe and Crowden Brook (Hudson and Cotton, MS.). The silty flaggy band with *Ct. stellarum* which outcrops in these sections was also found in the Alport boring, and is exposed in the Lothersdale Anticline (Bray, 1927, p. 55) and in Wharfedale (Hudson, 1934, p. 123). The fauna also occurs

[1] *Cravenoceratoides bisati* sp. nov. Holotype, Geol. Survey No. 49968, figured as *C.* aff. *edalense* by Bisat, 1932b, pl. i, figs. 4a–b. Locality, Throstle Nest, Silsden, Yorks. Horizon, near base of shales above Marchup Grit, Millstone Grit (Stephens *et al.*, 1942, p. 348); *Ct. nitidus* zone, Arnsbergian, Namurian. Description, Bisat 1932b, p. 33.

in Flintshire (Wood, 1936, p. 17), in South Wales (Ware, 1939, p. 174), in North Staffordshire (Hester, 1932, p. 38), and near the base of the Edale Shales of Dovedale (Bisat, 1932, p. 34).

N. nuculum zone.—The fauna of this zone is a complex one of closely similar forms. Above the *Ct. stellarum* subzone there are a group of forms, or a very variable species, collectively known as *Ct. nititoides.*[1]

The species apparently passes upwards into *Ct. fragilis* which is very common in the upper part of the zone where, however, it is associated with *N. muculum* and *E. bisulcatum* mut. β (Hudson, 1934, p. 123; Schmidt, 1933, p. 451; Stephens *et al.*, 1942, p. 351; Hudson and Cotton, 1943, p. 161) and is part of a distinct subzonal fauna which is widely spread throughout the south and mid-Pennines. Though originally included in the Upper *Eumorphoceras* beds, the upper part of this fauna is placed by some authors in the *Homoceras* Stage (Bisat, 1928, pl. vi; Stephens *et al.*, 1942, p. 350).

SABDENIAN (Bisat 1928, *emend.* Hudson and Cotton 1943)

These beds are well exposed in North Derbyshire (Jackson, 1927) and in the southern part of the mid-Pennines (Bisat, 1924; Moore, 1930). They were passed through in the Alport boring and their faunal subdivision has been discussed by Hudson and Cotton (1943, p. 158). Until the various unnamed forms which occur in the stage have been described and named, little can be added to that discussion. The fauna is abundant in Westphalia (Schmidt, 1933), Holland (Jongmans, 1928), and at Chokier in Belgium (Dorlodot and Delépine, 1930).

KINDERSCOUTIAN (Bisat 1928)

The fauna of Lower *Reticuloceras* (R_1) Age has recently been described in detail by Bisat and Hudson (1943) and the older subdivisions replaced by six zones. In order to give the subdivisions of this stage approximately equal value with those of the other Namurian Stages the older divisions of *R. inconstans*, *R. eoreticulatum*, and *R. reticulatum* are retained as zones and the newer subdivisions of Bisat and Hudson relegated to subzones. There is considerable uncertainty as to the distinctiveness and order of the various faunas in these subzones. In the *R. nodosum* subzone, for instance, the *R. moorei* beds of Samlesbury, near Blackburn, and of Ewood Clough, Todmorden, were formerly considered to be approximately the equivalent of the *R. nodosum* beds of Swint Clough, Alport: fresh evidence now suggests that they are below these beds. The fauna of this stage in Westphalia has been described by Schmidt (1933) and Hahne (1931).

[1] The type locality of *Ct. nititoides* is in the Wharfe Valley on the moorland between the Wharfe and the Washburn. Here, in the right bank of Pace Gate Beck, 280 yards upstream from Pace Gate Bridge, an isolated shale exposure contains *Ct. nititoides*, *E. bisulcatum* and a varied shale-phase fauna (Tonks, 1925, p. 251). The shale is towards the top of the Birk Hill Shales which occur between the Red Scar Grit and the Nar Hill Sandstone (Hudson, 1939, p. 326); it is not possible in this locality to relate its position to that of other faunas in the Arnsbergian.

MARSDENIAN (Bisat 1928)

The best account of the division of this stage into the well established zones of *R. gracile* (= *R. reticulatum* mut. α), *R. bilingue* (= *R. reticulatum* mut. β), and *R. superbilingue* (= *R. reticulatum* mut. γ) is by Wright and others (1927, p. 111). In most areas several faunas have been recognized in each zone, but their order has been confused by their terminology since they are usually referred to as the late α band, the early β band, etc., and in some cases it is not clear whether the " early " or " late " designates forms stratigraphically or phylogenetically earlier.

R. gracile zone.—Two faunas are usually found in this zone. In the lower one the characteristic form is often listed as *R. reticulatum* late mut. α (Wright *et al.*, 1927, p. 114; Hudson and Black, 1940, p. 290); this form is so-called because its horizon was originally erroneously considered later than the main horizon of *R. gracile*. It is also recorded as *R. reticulatum* early mut. α. *R. gracile* also occurs in the band, and it is therefore argued or implied that since *R. gracile* and its so-called early and late mutations occur in the one band they have no zonal value (Stephens *et al.*, 1942, p. 359). The upper fauna contains an abundance of *R. gracile* s.s.

R. bilingue zone.—There is again considerable confusion in this zone owing to the lack of precision in the use of the terms early mut. β and late mut. β. There are two distinct stratigraphical faunas in the zone, respectively above and below the Main Middle Grit, variously known in Yorkshire as the Pule Hill, Midgley, Woodhouse, or Brandon Grit and in Lancashire as the Revidge, Gorpley, or Fletcher Bank Grit. The recorded composition of these two faunas varies from place to place, either because of failure of identification, or of geographical variation on the one horizon or, probably, because the marine bands in which the faunas occur are diachronous. The lower fauna includes two faunal bands, the lower one containing *R. bilingue* and (or) *R. bilingue* early form together with a variant of *E. proteum*; the upper one contains R. *bilingue* and (or) *R. bilingue* late form. This latter form has been both figured and described by Bisat and, with his consent, is here given specific rank with the name *R. wrighti*.[1] The upper fauna is of widespread occurrence, and contains a form usually known as *R. reticulatum* late mut. β and *R. metabilingue* (Wright *et al.*, 1927, p. 115; Bromehead *et al.*, 1933, p. 150; Hudson and Dunnington, 1940, p. 211; Stephens *et al.*, 1942, p. 363). " Late mut. β " of this fauna may be conspecific with *R. wrighti*—it is referred to in the table of this paper as *R. bilingue* late form.

R. superbilingue zone.—In this zone the lower fauna, which has not often been recorded from Yorkshire, contains *R. metabilingue* dominant and *R. bilingue* late form (Wright *et al.*, 1927, p. 115). The upper fauna,

[1] *Reticuloceras wrighti* sp. nov. Holotype, C 25760, coll. British Museum (Nat. Hist.), figured Bisat, 1924, pl. vii, fig. 2. Locality, 725 ft. O.D., Pike Clough, Rishworth, Halifax. Horizon, Marine band in shales immediately above Readycon Dean Grit, Middle Grit Group, Millstone Grit. Description and comparison, Bisat, 1932, p. 120. Named in honour of W. B. Wright whose work, with that of his colleagues, on the Millstone Grit was the model for all subsequent work on the stratigraphy of that formation in the Pennines.

which is found in a widespread marine band, contains *R. superbilingue* and species of *Gastrioceras*, mainly *G. lineatum* (Wright *et al.*, 1927, p. 116). A fauna composed almost entirely of *G. sigma* occurs close above this band (Wright *et al.*, 1927, p. 116).

YEADONIAN (nom. nov.)

No name has yet been suggested for the beds of Lower *Gastrioceras*. Age, which contains the well-known *G. rurae* and *G. cancellatum* faunas. These beds are well exposed in the Yeadon Brick and Tile Works at Yeadon in the Aire Valley, which valley also contains the type localities of *G. cancellatum* and *G. crenulatum*. The name Yeadonian is therefore suggested as a stage name for the beds of Lower *Gastrioceras* Age.

G. rurae zone.—This zone includes the *G. cancellatum* and *R. superbilingue* fauna below and that of *G. rurae*, *G. cancellatum*, and *A. carinatum* above. The two are sufficiently distinct to be considered subzonal faunas. There is some evidence (Wright *et al.*, 1927, p. 124) of considerable lateral variation in the marine bands in which these faunas occur. This has been attributed by W. B. Wright to diachronism of the particular marine band, and if this is correct then the presumption is that the various goniatite faunas in the band in different areas are successive faunas within the subzone and are possibly equivalent, in the case of the *G. rurae* zone, to such faunas as those recorded by Wood (1936, p. 20), Jones and Lloyd (1942, p. 260) from Flintshire. In 1940 Bisat described *G. branneroides* from the base of the *G. cancellatum* subzone of North Wales and attributed its absence in other areas to overlap on an uneven grit floor, a suggestion that is supported by the complete absence in some areas of the *G. cancellatum* subzonal fauna (Hudson and Dunnington, 1939, p. 134; 1940, p. 212).

G. cumbriense zone.—The main fauna in this zone is that of *G. cumbriense* and *G. crenulatum*. In some areas, however, a lower fauna characterized by *G.* aff. *crenulatum* is also found (Schmidt, 1938).

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The Significance of Terraces due to Climatic Oscillation

By C. A. Cotton

West China Terraces

When describing river terraces in his recently published account of the "Ice Age in West China" Richardson [1] has assumed without question that in a period characterized by climatic oscillation wetter (and generally also colder) episodes result in aggradation and that degradation follows diminished precipitation.

Terraces of Fluvioglacial Origin

Correlation of phases of alluviation with glacial epochs, based on observed transitions and interfingerings of terrace and plateau gravels with glacial morainic deposits, is the very foundation on which the whole structure of the Penck-Brückner interpretation of Alpine Quaternary geology has been built.[2] Though some authors have thought it necessary to assume the occurrence of upheaval of the Alps in each interglacial epoch in order to explain the degradations that have left fluvioglacial gravels as terraces, it seems almost an inescapable conclusion that in Europe the climatic changes themselves have been mainly responsible for these. The thesis that episodes of alluviation may be correlated with glaciation and that terrace-cutting may be relegated to post-glacial time has been accepted by Davis.[3]

Investigators of Pleistocene geological history now generally start with a similar assumption, regarding it as axiomatic. In Paterson's generalizations of Pleistocene chronology, for example, the "major periods of aggradation" appear to be regarded as "coincident with glacial advance".[4] Bryan and Ray [5] also, in an elaborate and detailed geomorphic study undertaken in order to determine the age of an archaeological site east of the Rocky Mountains of Colorado, admit no possibility other than the correlation of downstream terrace gravels with substages of glacial advance. "The alluvial stream terraces," indeed, "can be traced continuously along the major streams . . . into the mountains, where each terrace ends at the moraine left by an ancient glacier" (p. 27).

"In any one period of valley glaciation the lower portions of the valley . . . are first filled with fluvioglacial debris and are thereafter, on the retreat of the glacier, more or less thoroughly cleared of this material" (p. 38). Each terrace, according to Bryan and Ray, "records a filling of the valley and a re-excavation to or below the present grades of the major streams" (p. 21).

These authors note that "each successive glaciation, *each less extensive*

[1] H. L. Richardson, The Ice Age in West China, *Journ. West China Border Research Society*, vol. 14 (Ser. B), pp. 1–27, Chengtu, 1943; reviewed in the *Geological Magazine*, lxxxi, 1944, p. 272.

[2] A. Penck and E. Brückner, *Die Alpen im Eiszeitalter*, 1909.

[3] W. M. Davis, *Die erklärende Beschreibung der Landformen*, pp. 431–2, 1912.

[4] T. T. Paterson, Geology and Early Man, *Nature*, 146, 1940, pp. 12–15, 49–52.

[5] K. Bryan and L. L. Ray, Geologic Antiquity of the Lindenmeier Site in Colorado, *Smithson. Misc. Coll.*, vol. 99, No. 2, 1940; L. L. Ray, Glacial Chronology of the Southern Rocky Mountains, *Bull. Geol. Soc. Amer.*, 51, 1940, pp. 1851–1918.

than the previous one, should be indicated by a terrace" (p. 38). [The italics are mine.] Clearly the case they discuss is only that associated with oscillation of an ice front during a final glacial retreat. As they freely allow, the effect of a fluctuating climate on the grades of streams "is as yet imperfectly understood" (p. 21). Nevertheless the results of such oscillation as they have studied may be directly comparable with terrace-making conditions in most perialpine regions. Such correlation of epochs of alluviation with a decrescendo of glacial advances appears justifiable, for example, in Burma, according to the conclusions reached by de Terra and Movius, which are in agreement with those of Dainelli and of de Terra and Paterson in the Himalayan region and in North-Western India respectively.[1]

HUNTINGTON'S PRINCIPLE

It may be urged with confidence that at least in certain cases an increase of precipitation will so encourage the growth of vegetation on catchment slopes in the headwater reaches of a river valley as to reduce their output of waste, and also that, even without such a reduction in the load to be carried by the river, higher precipitation will so increase the ratio of water to waste in the stream coming from the headwaters as to cause degradation down the valley; whereas a lessening of the ratio of water to waste in the stream, such as will be brought about by reduced precipitation probably aided by sufficient weakening of the vegetational protection of the soil in the catchment area to increase the absolute rate of supply of eroded debris, will cause overloading and result in aggradation of the valley. This deduction on Davisian lines is fully developed by Huntington in *The Climatic Factor*,[2] and it has been applied by him in the interpretation of terraced valleys.

It is important to note, however, that the reverse of these effects have been observed more lately in the semi-arid non-glaciated region comprising Arizona, New Mexico, and Trans-Pecos Texas by Bryan,[3] who correlates with prolonged droughts the arroyo-cutting episodes that have occurred there between stages of alluviation. In that dry region Bryan's observations have led him to the conclusion that "a slight change from the dry towards the less dry in climate is adequate to convert ephemeral streams from a condition of erosion to alluviation" and "lack of rainfall was the cause of cutting of arroyos".[4] The disagreement of the facts of this

[1] H. de Terra and H. L. Movius, Research on Early Man in Burma . . ., *Trans. Amer. Phil. Soc.*, 32, pp. 265–464, 1943 (reviewed by Kirk Bryan in *Journ. Geol.*, 52, 1944, pp. 140–1).

[2] Ellsworth Huntington, *The Climatic Factor*, pp. 23–36, Carnegie Inst., Washington, 1914; see also (by the same author) A Geological Reconnaissance in Central Turkestan, *Pumpelly's Expedition*, pp. 159–216, Carnegie Inst., Washington, 1905; and The Glacial Period in Non-glaciated Regions, *Bull. Geol. Soc. Amer.*, 18, 1907, pp. 351–388.

[3] C. C. Albritton and K. Bryan, Quaternary Stratigraphy in the Davis Mountains, Trans-Pecos, Texas, *Bull. Geol. Soc. Amer.*, 50, 1939, pp. 1423–1474; Kirk Bryan, Erosion in the Valleys of the Southwest, *New Mexico Quarterly*, 1940, pp. 227–232.

[4] Kirk Bryan, Pre-Columbian Agriculture in the Southwest as Conditioned by Periods of Alluviation, *Ann. Assoc. Amer. Geogr.*, 31, 1941, pp. 219–242 (pp. 236, 241).

case, of which the interpretation cannot be questioned, with Huntington's deduction has not yet been fully discussed.

Huntington's principle, as it may be termed, implies that all episodes of increased precipitation, including glacial epochs, will be characterized by degradation, at any rate in non-glaciated valleys. His contention is based upon an argument certainly applicable in places where, as Barbour [1] has expressed it, " conditions are so nicely balanced that erosion can start and be arrested again " as a protective cover of vegetation is depleted and re-established. It is obviously inapplicable, however, to those high levels at which the lowering of temperature in a glacial epoch inhibits the growth of protective vegetation or destroys such a pre-existing cover. Furthermore, in some regions well removed from those directly influenced by the operation of refrigeration and glacial erosion—the terraced valleys of Western China being a case in point—the vegetation may be too little modified by climatic oscillation to affect its function of protecting the soil from erosion, whereas when precipitation increases beyond a certain point flood erosion and accelerated mass movement will swell the output of waste out of proportion to the accompanying increase in the volume of off-flowing water, thus causing aggradation even in valleys that receive no gravel of fluvioglacial origin.[2] In such regions it would seem that pluvial periods, whether contemporaneous with glaciations or not, may be periods of accumulation of alluvium which is afterwards left stranded on terraces when rivers proceed with the vertical incision of their valleys in later surges of erosion.

Conclusion

In conclusion it may be said that there are very good reasons for accepting in the case of many terraces an explanation of their origin based on a climatic as opposed to any tectonic hypothesis. In view of the uncertainties involved it is not always clear whether alluviation that has preceded terrace-cutting is to be attributed to increase or shrinkage of precipitation ; but a dogmatic adherence to the deductive principle embodied in Huntington's argument is by no means justified.

Postscript

Since the foregoing note was written it has occurred to me that some remarks might be added on the " power-volume " doctrine of Paterson.[3] One can but admire the presentation of this author's general thesis, but it is a matter for regret that important questions relating to alluviation and terrace-cutting are dismissed in too summary a fashion. Some of the arguments seem fallacious, though perhaps an expansion of the presentation would clear away difficulties.

Most observers of fluvioglacial and periglacial terraces (who generally use the term " terrace " as synonymous with " alluvial gravel deposit ")

[1] G. B. Barbour, The Geology of the Kalgan Area, *Mem. Geol. Surv. China*, Ser. A, No. 6, 1929, p. 119.

[2] Dr. H. L. Richardson has outlined this hypothesis in conversation.

[3] T. T. Paterson, On a World Correlation of the Pleistocene, *Trans. Roy. Soc. Edin.*, 60, 1941, pp. 373–425.

correlate the episodes of aggradation in which these have been formed with glacial advances. This, for example, is Zeuner's interpretation of river terraces in Silesia, while in Thuringia "phases of climate only slightly cooler than normal found their representation in a terrace".[1] Paterson appears to break away from this usage when he dates terraces, T 1, T 2, T 3, from the phases of degradation in which terraces are cut and gravels are left stranded on the terrace treads. These degradational phases he correlates with episodes of high (or increasing) precipitation. Nevertheless, in his development of the theory of an association of twin terraces with double glaciations in accordance with Simpson's meteorological theory (p. 420 and fig. 23) Paterson indicates that he also regards some phases of aggradation as synchronous with glacial advances. Specifically, his curves show correlation of phases of aggradation (in valleys subsequently terraced ?) with episodes of dwindling precipitation, while degradation is assumed to occur whenever precipitation is increasing. The curves show "cold-dry" aggradational episodes in periglacial regions synchronized with glaciations, though each has been immediately preceded by a "wet" episode of valley incision.

Paterson's theory of river regimes is stated, though all too briefly, on p. 375 of the work cited. As many weighty arguments hinge on this statement, it may fairly be subjected to some criticism. It is announced as a generalization that an increase of precipitation will act in the same way as "orogenic heightening" in producing such an augmentation of erosional energy ("power-volume" of Paterson) as will lead immediately to "greater corrosion". The use of the word "heightening" suggests that the author means no more than such a change of elevation as might result from eustatic movement. This would not immediately cause an increase of erosional energy inland. If "orogenic" is used, however, in the strict sense (contrasting with epeirogenic), then heightening no doubt implies also deformation with sufficient steepening to accelerate erosion in at least some headwater streams. Whether increased precipitation will act in the same way seems to depend on local circumstances which Paterson has ignored in formulating his generalization. If Huntington's principle could be accepted without reservation, then degradation for the greater part of the length of the course of a river might be expected. This would follow, however, only as a result of either a reduction or maintenance without notable increase of the rate of denudation on the catchment slopes, and Paterson does not seem to subscribe to this part of Huntington's hypothesis. Rather he seems to imply accelerated erosion on land slopes feeding rivers. Notably he recognizes widespread solifluction in periglacial regions at times when "power-volume" has been high. Paterson affirms, moreover, that the first effect of increased precipitation ("power-volume") will be an association of degradation in the "upper zone" of a river valley with aggradation farther downstream.

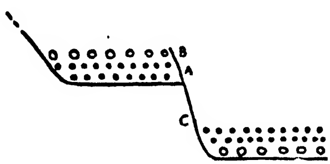
It is perhaps conceivable that in some circumstances aggradation in the middle and lower valley can be accompanied by degradation in upper

[1] F. E. Zeuner, The Pleistocene Chronology of Central Europe, *Geol. Mag.*, lxxii, 1935, pp. 350–376 (pp. 358–9).

reaches. This, however, implies the development of a gradient gentler than that formerly existing in the valley as a whole, and may involve difficulties when the whole profile of the river is taken into account.

In an "ideal river profile" (Paterson, p. 375), which presumably means a graded, or mature, profile, one cannot postulate that *deposition* will be in progress in any part, whether "lower", "middle", or "upper". An ideally graded river is indeed *transporting*, but not permanently depositing, gravel, sand, and silt. The transverse profile of the upper course of the river, as shown in Paterson's fig. 1, correctly enough implies the presence of no more than a veneer of gravel which has been in transit and has been left by rejuvenation stranded on a flat floor cut by lateral stream corrasion. It dates from the time immediately preceding the rejuvenation which left it so stranded (compare the Nile terraces—Paterson, fig. 18).

The section reproduced herewith represents conditions (as deduced by Paterson) in the "middle zone" of the river course after a rejuvenation has taken place which has resulted from a "further increase of power-volume". It shows, perhaps correctly, some finer gravel or sand (postulated



Text-fig. 1.—Paterson's "section across the river channel" in the "middle zone" of a river valley.

as a deposit normally laid down by this river in the "middle zone" of its "ideal profile") lying on a former cut-rock floor which has now been left, with its cover, as a terrace. According to geomorphic principles that have been widely accepted there is no reason for showing this as passing upward into coarse gravel, for the immediate effect of the first "power-volume" change postulated would be degradation such as would result in the stranding of the valley-floor fine-gravel or sand veneer on the terrace tread; but if the first "power-volume" change has produced aggradation instead of degradation, as seems possible in some circumstances, then the layer A, B may be correctly shown as thickened, and possibly the bulk of the gravel so deposited will be coarser than that at the base.

No explanation has been given of the generalized postulate of a change from aggradation to degradation in the middle zone (responsible for the cutting of the terrace front C, and a very critical stage in terrace-making) which is casually referred to a "further increase of power-volume" after the first, which has here produced aggradation. There is a reversion here to erosion according to Huntington's principle, which conceivably has been delayed by some special circumstance in a particular case; but such a reversion cannot fairly be included as part of a broad generalization of the geomorphic consequences of cyclic variation of precipitation. Assuming this as a possibility in a special case, however, it will be found

next that one is not told how after such degradation has taken place a floor is developed for the reception of future gravel accumulations (D, E in text-fig. 1). Presumably a stable gradient is established, and lateral corrasion supervenes. It is not easy to see, however, why this floor, gradually developed as it must be in a long period of mature meandering, is found to be veneered with very coarse gravel (D) instead of the fine gravel or sand formerly deposited in this zone and characteristic of the " middle zone " of the " ideal ", or graded, profile.

The next change postulated is a decrease of precipitation (" power-volume "), which is made responsible for an ensuing aggradation. Logically this follows upon either increase of load to be transported or reduction in transporting power of the river, however brought about, and here Paterson's theories are again in accord with Huntington's principle. Gravel again overlies a flat floor of cut rock ; but there seems to be no reason why any of this gravel (D) should differ materially in coarseness from that left as A after an earlier valley-floor planation. The lowest layer, D, was present before aggradation set in, when it was gravel *in transit* to the extent that it consisted of flood-plain deposits subject to repeated reassortment by a stream with an ever-changing, meandering course. It consisted of no more than a veneer of gravels, etc., which must have been of a fineness characteristic of the " middle zone " of the well-graded river. It is difficult to understand, moreover, why this probably fine gravel (or sand) should pass upward into anything conspicuously finer where it is covered by the deposits of an aggrading river. The theory of progressively increasing fineness upwards in extensive alluvial accumulations seems quite inapplicable to river-valley deposits in a " middle zone ". That widely spread river-laid sediments become progressively finer during the course of a diastrophic cycle may be a safe induction. Whether the same is true for a precipitational cycle or not, some geomorphologists seriously question its soundness as applied to the gravels in river terraces.

In the examination and study of river terraces there is an ever-present danger of mistaking flights of step-like terraces such as may be cut in previously deposited alluvium during a single episode of deep degradation for successions of terraces each with cyclic significance. The whole question of constructional terraces is a controversial one which has not been thoroughly explored. Fisk,[1] an American disciple of the European school of Depéret who has flouted the dictum of the master Gilbert that " river terraces as a rule are carved out, and not built up ", has interpreted a succession of terraces in Louisiana as constructional and has satisfied himself that they are built of materials that are progressively finer towards each upper surface, or terrace tread. The late Professor Douglas Johnson, however, remained unconvinced on this point after examining the field evidence.[2]

Johnson also held views such as are considered unorthodox in Europe on the nature and origin of the terraces bordering the rivers of France, a country he knew extremely well ; and these views he very tactfully

[1] H. N. Fisk, Depositional Terrace Slopes in Louisiana, *Journ. Geomorph.*, 2, 1939, pp. 181–200.
[2] *In litt.*, 1939.

communicated to his French colleagues.[1] He was reported as saying that, " No feature observed seemed incompatible . . . with the theory of deep valley fill followed by progressive erosion in a single uninterrupted cycle. . . . Professor Johnson . . . hoped that those whose broad and detailed knowledge of the areas gave them special competence would give hospitable and friendly consideration to the alternative possibilities suggested." In the case of cut terraces, " since the river reworks the surface of each terrace to a depth equal to the depth of the river channel, . . . mixed faunas or abnormal distribution of faunas may result ; fine sand and silt, stratified or unstratified, may represent calm flood-water deposition in the back-swamp areas . . . and contrast strongly with the underlying gravels without indicating any significant change in the regime of the river." I do not know to what extent those European geomorphologists who have concerned themselves most with the investigation and interpretation of river terraces have accepted this invitation to introduce into their studies the analytical method of multiple working hypotheses.

One aspect of the problem presented by cyclic terraces that is rarely referred to is the possibility (which must be a certainty in some cases) that constructional treads have been planed down during some halt in the terrace-cutting degradation. By this means much (the upper half, perhaps) of the gravel accumulated in an aggradational stage will be swept away, and the flood-plain gravels of the intermediate or planation episode which will be left on the lowered tread will be of comparatively late date and strongly disconformable on the remnant of the aggradational gravels. This is, of course, only a special case, though perhaps a very common one, of the well-known process which cuts defended, meander-scar terraces during the degradation of a valley fill. Such planation has taken place on an enormous scale in the aggraded intermont basins of North Canterbury, New Zealand,[2] of which the largest example is the Culverden basin plain, 300 square miles in extent.

Discussion : The Significance of Terraces due to Climatic Oscillation

By H. L. Richardson

WITH regard to the relation between climatic oscillation and terrace formation, some ideas that I have collected in the course of studying accelerated (man-made) erosion, may be useful in a geomorphological setting. Huntington's principle and the idea I used in my paper "The Ice Age in West China" are not necessarily opposed, if one limits the application of Huntington's principle to semi-arid regions which are just on the margin of being able to support a vegetative

[1] Douglas Johnson, in " Terrasses de la vallée de la Seine et de la Somme" (CR. de l'excursion B2), *CR. Cong. Internat. Géog. Paris* 1931, 2, 1933, pp. 175–221 (pp. 202–3).

[2] C. A. Cotton, *Landscape*, 1941, p. 178.

cover. In such regions a further decrease in precipitation, leading to serious reduction in the protection afforded by vegetation, would accelerate erosion on hillsides and steep valley floors, and this in turn would lead to deposition of spoil on more gently sloping valley floors lower down. A further oscillation of the climate, in the direction of increasing rainfall, would restore the vegetative cover, reduce erosion, reduce the load in the rivers, and allow downcutting to continue. But a still further increase in precipitation might be expected to increase erosion of the type associated with landslips and flooded streams and rivers ; once more increased load will be swept down from the steeper hills and stream-beds to the lower and gentler slopes of the rivers, where it will be deposited. In other words, one may say that there is a level of precipitation, probably a moderately low one, at which (apart from human interference) there is a close vegetative cover and geological erosion is at a minimum ; any appreciable departure from this level of precipitation in either direction will cause increased geological erosion in the upper courses of streams, and hence increased deposition in their lower courses.

The swiftly flowing upper reaches of a river (and the run-off on steep hillsides) are likely to have an erosive power out of proportion to their volume, as contrasted with the more voluminous but slower flowing middle and lower reaches. It follows that spoil will be deposited in the more level parts of a river, where alluvial plains are built up, at those times when erosion is most active in the headwaters ; and, apart from other factors, any climatic factor that gives increased energy to erode will operate more strongly in the headwaters of a stream, causing erosion there which will be followed by deposition lower down. It is when erosion is at a minimum in the headwaters that degradation can take place in the lower course of the river. This will be under conditions of moderately low rainfall or when the rainfall is tending in that direction from either very low or high rainfall levels.

I am assuming that increases in both erosion and deposition can take place simultaneously in different parts of the same watershed. This is justified by my observations of accelerated erosion (man-made), and I think it is likely to represent what happens in nature. Thus an increase in run-off may increase the carrying power of the water in the upper parts of a stream ; but it also increases the load to such a degree that in the lower parts the stream is likely to be overloaded. It is also assumed that we are dealing with river systems which, rising in hilly or mountainous country, are still far from grade. In such country landslips and the cutting of valley-sides by flooded rivers can take place in spite of dense vegetation when heavy rain falls—as one may see, for example, on the West Coast of the South Island of New Zealand. With increasing precipitation, during climatic oscillation, there are likely to be more heavy downpours and hence more erosion and deposition of this type.

Another factor that has to be considered, although it is only of the second degree of importance as compared with total precipitation, is the distribution and intensity of the rainfall. This might cause certain departures from the general principle of minimum erosion stated in my first paragraph ; it also affects the interpretation of Huntington's principle. An increase in rainfall from dry to less dry, or moist, might actually

give the streams less energy to erode, since most of the erosion and transport takes place during the periods of flood or maximum flow, and the " flash floods " of a semi-arid climate might be larger than the ordinary floods of a somewhat cloudy, humid climate. This would delay the reappearance of erosion and deposition with increasing rainfall which is required by my hypothesis. But eventually, as rainfall still further increased, the number and volume of the floods would reach the point where there was again increase in erosion and deposition.

One has to consider also the relation between the rate of change of climate and the rate of lowering of the headwaters of a river. The first effect of increased erosion at the head would be aggradation along the lower course ; but in course of time, if the climate changed very slowly, the transport of material from the upper to the middle or lower course of the river would reduce the slope of the former and increase that of the latter until the carrying power of the water in the lower reaches was sufficient to deal with the smaller load brought down from the upper reaches, and after this stage was passed degradation would proceed in the middle and lower reaches also. But it seems that in regions where dissected high-mountain topography is present the rate of climatic oscillation is faster than such a change in the gradient of a river.

Naturally many other factors of importance in terrace-formation, such as differential earth movements, or earthquakes that dislodge extensive landslips, may also come into the picture. I have been trying to consider the influence of climate apart from these. It is assumed to start with that we are dealing with inland or continental rivers which are " insulated " from the effects of changes in the relative levels of land and sea by the length of their lower courses or by gorges like those of the Yangtze or by both.

The Granite Problem

By R. H. Rastall

THE following pages have as their text three Presidential Addresses by Professor H. H. Read. The first, entitled *Metamorphism and Igneous Action*, was composed for Section C of the British Association at Dundee. The other two entitled *Meditations on Granite*, Parts I and II, were read to the Geologists' Association in 1943 and 1944. They will be referred to for brevity's sake as Dundee and Granite I and II.

A Presidential Address usually has and certainly ought to have a personal note, and it seems only logical to adopt a similar tone in any discussion of the same. Therefore, no apology will be offered here for a frequent use of the first person singular in what follows, since this consists very largely of my own reactions to recent developments of a very old question, the origin of granite and kindred problems, and to what at first sight appear to be highly revolutionary notions. It is clear, however, from these addresses that many of these notions are not so new as their authors think. Petrologically I was brought up in the straitest sect of magmatism, with Rosenbusch as its major prophet. All igneous rocks were formed from magmas and all plutonic rocks were bodily intrusions which made room for themselves by shoving aside or lifting the surrounding rocks. Porphyritic structure indicated crystallization in two stages and local variations of composition and associations of cognate rock types in igneous complexes and petrographical provinces were due to magmatic differentiation. Also metamorphism was sharply divided into two distinct categories, thermal and dynamic. Petrologists then employed themselves mainly in describing and naming new and *interesting* varieties, the highly alkaline rock-types being specially popular, as they provided opportunities for the invention of names like umptekite and jacupirangite. Much stress was also laid on the separation of igneous rocks in general into two major groups, alkaline and calc-alkaline, or Atlantic and Pacific. Altogether the teaching had a strong German flavour and the French school was ignored. American petrology was then only beginning to be heard of.

In the elementary teaching of petrology the question of classification has always presented a special difficulty, since there is no such thing as a definite rock-species. The weak point of Harker's *Petrology for Students* from this point of view was that it contained no detailed classification such as could be used in reading for examinations. The chapters just followed on without any real explanation as to why they did so. Harker was much too philosophically minded to commit himself to hard and fast boundaries where he knew none such existed, but students demanded something of the sort. At this time of day there can be no harm in saying that I myself constructed the pigeon-hole tabular classifications that appear in the 5th (1909) edition of Hatch's *Petrology of the Igneous Rocks* and naturally a very similar plan was used in my own *Text-book of Geology* written jointly with Mr. Lake (1910). As both of these books have had a wide circulation many geologists must have got their first notions of the igneous rocks from them, and I cannot help feeling a certain

amount of responsibility for the wide dissemination of the statement, implicit if not explicit, that all granites are derived directly from intrusive magmas, without any hint that a similar rock might be formed in other ways.

At any rate the fact remains that for a long time all the geologists I knew apparently took it for granted that all granites were formed in the same way, by the crystallization of intrusive magmas, and that gneisses were due either to flow of heterogeneous magmas or to the recrystallization under pressure of sediments or volcanic rocks, without much change of composition. In certain cases pneumatolysis was admitted. The foregoing is of course a gross over-simplification, but I think it does fairly represent the state of mind of most students at the end of their University courses about forty years ago.

But for the present, enough of personalities. To return to the three Addresses, Granite I begins appropriately with a discussion of " what is granite ". Many modern definitions are quoted and finally boiled down into a synthetic form as a summary of current views : it is as follows, slightly but I think fairly condensed :—

" A granite is a deep-seated igneous (or eruptive) rock composed of quartz, alkali-felspar and a ferromagnesian mineral, with visible granular hypidiomorphic texture."

It is here to be noted that continental authors (and Professor Shand) use the word eruptive as including intrusion and possibly as including a good deal more if it is intended to be applicable to some theories of granite formation. A discussion of this point really opens up the whole field of the present inquiry. It is to be presumed that the British and American word " igneous " is intended to imply " once molten " or something like that. The word igneous is in itself most inappropriate since *ignis* means fire, and nobody now supposes that combustion has anything to do with the origin even of lava.

The next section begins with a full discussion of the work of four British geologists, two Scottish, Hutton and Lyell, and two English, Clifton Ward and A. H. Green. It may be taken that Hutton was the man who finally squashed the Neptunist school and established the igneous, i.e. the high temperature origin of granite. His work is so well known as to need no criticism here. It was really the first application of common sense to igneous petrology, and especially to granite.

Lyell's views, which showed some variation from time to time in the successive editions of his books, are discussed at considerable length ; and in some ways it may be said the earlier versions were the more modernistic. He at least admitted the possibility that granites might be formed by metamorphism in the broadest sense. Since these ideas recur in considerable force in the final summing up at the end of Granite II, a consideration of them may be deferred for the present.

It is pleasing to find a full discussion of the work of Clifton Ward in the Lake District, to which scant justice has been done in the past. I first became acquainted with this work about 1904, and if it made no particular impression on me at the time it at least opened my eyes to the fact that some competent authorities held what may be called metamorphic theories of the origin of granite. To quote from Granite I, page 70 : " In his

studies of the Lake District granites (1875, 1876) Ward propounds ideas which tricked out with a little modern terminology and further spiced with a dash of physico-chemical jargon, would find considerable favour with the most revolutionary of to-day." He says that the Eskdale and Shap granites were produced in great measure at all events by extreme metamorphism of the Borrowdale volcanics. The Skiddaw granite on the other hand might have been produced at a greater depth and eaten its way upward. This qualification arose from the fact that it was difficult to see how a granite could be formed from Skiddaw Slates. As a matter of fact the Skiddaw granite could not have been formed directly from Skiddaw Slates. In the rarely visited large exposure in the upper Caldew valley (Skiddaw Forest) the granite is clearly overlain by a very considerable thickness of gritty rocks : it is only in the smaller apophyses, to which most attention has been directed, that it comes in direct contact with the slates. Moreover there are in the Skiddavian Series as shown by the recent survey great masses of coarse grits, the Watch Hill grits, admirably adapted for melting down to granite. Again, the Skiddavian must rest either on Ingletonian rocks, which are 10,000 feet thick only twenty miles away, or on the Archaean. As a matter of fact also there is a good deal of difference between the muscovite-bearing very acid Skiddaw granite and the Shap rock which is rich in biotite, has only about 68 per cent SiO_2, and is generally described as adamellite or granodiorite. Both these rocks will be mentioned again later. Ward clearly recognized the possibility of the addition of material from below in the manufacture of granite, and enumerated three different conditions under which rocks occur with regard to metamorphism. These are, very much abbreviated :—

Igneous fusion ; aqueo-igneous fusion, not above red heat ; and permeation by water well below red heat.

The first condition is exemplified by molten lava and includes what we should now call dry melts. The second and third both seem to come under the modern term hydrothermal.

In the discussion of Ward's paper Judd said the relations were consistent with a totally different conclusion. This remark has a familiar ring, having been made in almost every such discussion before and since, and it is in fact a precis of the present controversy.

A. H. Green recognized three types of granite which may be described in the briefest possible terms as follows : (1) banded granite, due to not very severe metamorphism of bedded rocks. (2) What he calls granite in amorphous masses, obviously meaning masses without definite boundaries, attributed to a higher grade of metamorphism than (1), but not having reached fusion. (3) Obviously intrusive, having been metamorphosed to fusion point. It is to be noted that Green uses the word metamorphism in all three definitions, thus attributing the liquid form (magma, though this word is not used) to melting by intense heat (and pressure ?) of pre-existing rocks. This is much the same as Ward's views. It is to be noticed that Green does not specify what kind of rock when melted gives granite magma, while Ward seems to think almost anything will do. Some of the things said at a very recent discussion at the Geological Society on part of the coast batholith of British Columbia

sound very much like all this, though there the magic word is mostly granodiorite and not granite. In another place Green definitely said that some granites are plutonic and some metamorphic.

The object of the foregoing summary of the work of what Read calls the Lake District school is to show that in comparatively recent times there were British geologists, and good outdoor men too, who believed that granites can be made by alteration of older rocks. Green's banding seems to imply sediments, and Ward explicitly discusses how granite could be made from Skiddaw Slates by " addition from below of some of those elements which were lacking in the original slate ".

It is obviously impossible to give here a full account of the ideas of the French school, and it is unnecessary since in Granite II Professor Read summarizes the whole thing in a most lucid way, with much stress on the wonderful year 1847, which was marked by the appearance of several epoch-making publications. A petrologist could not better celebrate the liberation of France from German tyranny than by reading this literature and giving it a fair and open-minded consideration.[1]

As early as 1824 Ami Boué put forward ideas approaching closely to the conception of granitization as now understood, and by 1837 Fournet had come to the conclusion that rocks very much alike, e.g. gneisses, may be of different origins, now an important point. In 1841 came Ste-Claire Deville's fruitful idea of mineralizing agents, which jointly with Élie de Beaumont's paper six years later gave rise to all modern developments of pneumatolysis and the theory of ore-deposits.

Later Michel-Lévy, Lacroix, Barrois, Duparc, and Termier all put forward ideas diametrically opposed to those of the German school, which was so much favoured in England and America. One of the most fundamental of these doctrines can be summed up in the word granitization, and it will be well at this point to be quite clear as to what is meant by this word. Here is Professor Read's synthetic definition derived from analysis of many sources.

Granitization means the process by which solid rocks are converted to rocks of granitic character without passing through a magmatic stage.

It is clear that all this opens up an enormous field for discussion since the French school and a rapidly increasing number of writers in other countries maintain that granites can be formed from a wide range of rocks. In many discussions one point is often left rather obscure, namely, the extent to which what are commonly called gneisses are to be included in the granite category. As a matter of fact nearly all granites, even the most uniform, show more or less of a parallel structure of some kind if the specimen examined is big enough. Ordinary hand-specimens out of cabinet drawers are often most misleading in this respect. Sometimes it takes a whole quarry or cliff to show the pattern, but it is generally there if looked for. All of this is very often attributed to flow during intrusion, or to convection currents in the magma and that kind of thing: when very acute to the mixing of magmas. It looks as if the present distinction into orthogneiss and paragneiss is going to break down.

[1] This sentence was written on the day of the liberation of Paris, 26th August, 1944.

It always seems that the least satisfactory part of all this discussion about emanations and mineralizing fluids and the rest of it is that we do not know where they are supposed to come from. One point does suggest itself: if these fluids can turn almost anything into a granite, it seems probable that their own composition must be something like granitic, and therefore they may arise from the lower part of the sial. It is to be noted that some French writers use felspathization as almost synonymous with granitization.

After all there is nothing mysterious about felspathization if the principles of physical chemistry are applied. Felspar is a stable phase in a wide range of systems of the components SiO_2, Al_2O_3 and alkalis at high temperatures and pressures and therefore can crystallize in almost any environment. This gets over the difficulty felt by some in the development of felspar in both igneous rocks and metamorphosed sediments. When silica and alkalis are high the result is quartz and felspar.

Here a highly-scented red herring could be drawn across the track by asking if there is such a thing as a true granite without muscovite. There are also the soda-rich highly siliceous rocks with arfvedsonite, aegirine, and so on. There seems to be no explicit reference to these in the writings under review, and since there is, for example in the Oslo region, so well accepted a relation between them and the highly alkaline intermediate and basic rocks the question seems to call for consideration. The bearing of such groups on the problem of magmatic differentiation is obvious.

Another non-granitic rock type that occurs in very large masses in some places is anorthosite. This consists mainly of plagioclase felspar and therefore presents no difficulty as to felspathization, but the point that suggests itself here is this: many of the more basic types of anorthosite show so close a relationship to other more "normal" (i.e. more easily pigeon-holed) types like gabbro and eucrite that it is difficult to see where the ardent "granitizer" is going to stop.

It is not proposed here to enter into the question of the different kinds of metamorphism, which has now got so tangled up with the granite problem. To some extent it is a question of nomenclature, arising from a want of precision, and possibly in part to muddled thinking on the part of various writers. If granite has been made by alteration of older rocks, the exact name to be applied to the processes by which that alteration was brought about does not matter much. Frankly I feel some considerable difficulty in visualizing any process by which a higher grade of metamorphism can overlie a lower grade, as Read describes more than once. This is not of course casting any doubt on the accuracy of the observation, but merely stating that I cannot see how it is brought about.

However, what we are now concerned with is the question whether rocks of different kinds can be converted into granite by the action of what we may here for convenience call mineralizing agents. This raises indirectly what may be called the room problem. For many years past I have been troubled by this, especially in the case of great batholiths. In some cases this difficulty has been circumvented by saying that these are not really batholiths in the sense of a bottomless mass, but flat sheets so arranged as to look like such. But this really will not work in the case of the biggest ones. Actual cases cannot here be discussed in detail

but often the only possible explanation seems to be that the granitic (*sensu lato*) mass gets wider and wider downwards and eventually merges in depth with the sial in general.

On the broadest lines it seems to me that one of the main points of the earlier French school is that there is no real distinction between plutonic and metamorphic rocks as generally defined, at any rate so far as the acid members, namely granite and granitic gneiss, are concerned.

From all this literature it seems that according to French authorities granitization of older rocks is accomplished by two chief processes, which can be conviently summed up as lit-par-lit injection and bodily replacement of minerals, not necessarily all the minerals, by purely chemical action. Lit-par-lit injection necessarily implies that there must be some kind of banded structure to start on, either sedimentary lamination, cleavage, or schistosity. Of course it may take either of two forms; either forcible injection along planes of weakness, which without chemical action as well would imply an increase in the total bulk of the rock; or removal by solution and replacement of some more susceptible layers, which need not alter the total volume.

But besides this we have the possibility of chemical replacement of some or all of the minerals by permeating agencies, to use a term as vague as possible. It does not really matter whether these are called vapours, fluids, or liquids since the processes almost certainly go on above the critical point of water, about 375° C. and (roughly) 200 atmospheres. This temperature is barely that of visible red heat, and the necessary pressure is reached at quite a small depth. It is rather curious that in all these discussions the critical point is never mentioned. Many years ago Arrhenius suggested that water at high temperatures becomes chemically very powerful. Now it is clear that if material is to be added to rocks by what may be called molecular replacement something must be removed, and recent literature affords endless examples with analyses and calculations referring to this subject. But after all it is not clear why so often, one may say almost always, the result is a granite.

The processes by which rocks are granitized are described by French writers as imbibition, oil-spot mechanism, and so on. The first of these terms somehow grates a little on British ears, but it seems to mean what in this country is commonly called soaking up, like a sponge.

We are now led on to the key word of the modern literature, Migma. The literal translation of this is mixture, and it appears that it is usually conceived as a mixture of magma and the products of the breaking up or melting of pre-existing rocks. However some writers, especially Niggli, consider that participation of a magma is not necessary, because the liquid part can be obtained from the pre-existing rock: at least that is what I understand him to mean, though it is not obvious to me why this should be considered as a mixture. One underlying idea seems to be that the rock has a patchy appearance, and may be permeated by veins derived by special concentration of portions of itself. The definition of migmatites given by Sederholm in 1926 is that they look like mixed rocks and originate by the mixture of older rocks and a later erupted granite magma. The literature of migmatites is now very large and includes some very lively controversies which cannot be discussed in detail here,

between Sederholm, Holmquist, Wegmann, Niggli, Backlund, and von Eckermann ; in all this the problem of the Rapakivi granites and of big felspars in general plays a considerable part. This last item will be mentioned again later.

Since the petrology of the ancient Finnish rocks, which form part of the Fennoskandian Shield, plays so considerable a part in all this, it may be permissible to mention here a point which has long seemed to me to be of great importance, namely, the suggestion of greater igneous and metamorphic action in Archaean times than at any later date. I seem to remember a good deal of scorn being poured on geologists, for example Professor Bonney, who were very sceptical as to the formation of true gneisses in any later periods. These people possibly went too far in this direction, but it seems possible that they were nearer the truth, and that there really is a fundamental difference between the metamorphic rocks and more especially the granitic rocks of the Archaean and those of later revolutions. In many modern writings of a general character in what may be called international geology there is a distinct tendency to stress the differences between the ancient continental blocks on the one hand and the geosynclines and shelf areas on the other. It is pleasing to find that Professor Daly is at least not hostile to the idea of greater activity in Archaean times. The principle of uniformity has probably been pushed too far, and I think even Lyell would not raise any violent protest against this slight modification of it.

As just mentioned, the problem of big felspars has attracted much attention of late. I am quite incompetent to touch on the Rapakivi question as I have not read the literature and have seen few specimens, but there are two instances mentioned by Professor Read which I have myself seen, on which I should like to make a few observations. Firstly, in 1910 Drs. Rogers and du Toit took me to see the famous section at Sea Point, Capetown (Darwin's section ; see Plate X of du Toit's *Geology of South Africa*), and to put it briefly, for the life of me I could not see how those felspars got into the Malmesbury rocks ready made. This was really the first thing that shook my faith in the unmitigated doctrine of the intrusive magmatic origin of granite. The other point concerns the big red felspars in the Shap granite and in the dark rounded basic patches attributed by Harker and Marr to derivation from a more basic underlying magma. As I understand Professor Read, he considers that these " clots " as well as the obvious xenoliths are all different degrees of alteration of the surrounding rocks and that the red orthoclase crystals grew in them. My objection to this is that the felspars in the rounded clots are always deeply corroded and surrounded by reaction zones, sometimes almost reduced to vanishing point, as they also are in the associated basic dykes. I do not venture to suggest the true meaning of this effect, but I do suggest that it is a matter requiring attention in view of the laws controlling mineral stability. Furthermore according to my recollection, when a big enough section of the normal granite is seen there is a distinct tendency to a flow arrangement of the phenocrysts. Here again hand specimens are misleading, though shop-fronts are better, but even these may be cut unfavourably. Another matter at Shap that seems to require further investigation is the andalusite-bearing

rock and the general streaky mess on the east side of the granite, both referred to by Harker and Marr.

But to return to the migmatites and the general problem of granitization, whether in Finland or elsewhere. The fundamental idea here boils down to this: that rocks that were once presumably in a solid and stable state have been so acted on by physical and chemical agents that they have again become unstable, and are either mechanically broken up or so strongly heated and subjected to such powerful chemical agents that their composition is altered; they are raised to a temperature approaching fusion; and are eventually recrystallized with different forms and structures. To these processes, with their variants, many special names are applied. It will be well to consider these briefly. The following definitions are taken from Holmes's *Nomenclature of Petrology*, 1920, and the references there given are to a publication by Sederholm in 1907.

Anatexis. An ultrametamorphic process in which deep-seated rocks are remelted by the emanation of heat and hot gases from below, thus providing regenerated magmas *in situ*.

Palingenesis. The rebirth of a magma *in situ* by the fusion of pre-existing rocks such as granites, gneisses, and schists.

These seem to be identical, and Read suggests that palingenesis should be dropped. It is evident that both are not necessary, but for no very clear reason I rather prefer it to the other.

To these may be added *syntexis*, a term due to Loewinson-Lessing, 1896, which shortly means a mixed melt, whereas anatexis is taken to be a melt of one kind of rock. The distinction seems unimportant. From the same source comes Sederholm's original definition of migmatite: a term applied to composite rocks, such as gneisses, produced by the injection of granitic magma between the folia of a schistose formation. It is obvious here that migmatite has undergone a change of meaning, since this definition is equivalent to lit-par-lit injection, a sense narrower than the present usage. Here also there is no mention of ichors, but only of magma, and no definite suggestion of chemical change, or metasomatic replacement. Sederholm's later definition of migmatite has already been given on page 24. It does not seem to be quite clear what exactly is now to be taken as the accepted definition of migmatite.

Another point in need of elucidation is whether the Fennoskandian and the French ideas of a granite magma are the same. The earlier French writers did not use the word, but the later ones, especially Lacroix and Termier, do. As I understand their idea the magma in the French sense makes itself as it goes along, so to speak, by the action of what they call emanations on pre-existing rocks. (Colonne filtrante; cortège d'émanations transformatrices and so on, which I take to be the same as Sederholm's ichors.) But the definitions quoted above seem to imply a ready-made magma which comes along from some unexplained source and does the work attributed to the French emanations. One consideration here seems important: if the original rock is very different from granite the mere addition of a magma of granitic composition could not convert the whole thing into granite. There must be something to balance the non-granitic fraction, and then the question arises, why is the result

always granite? Sederholm definitely said that there are no basic migmatites. This seems to exclude the amphibolites from this category.

Several writers, including Professor Read, have observed almost plaintively that although sediments in geosynclines have obviously been depressed to enormous depths they refuse to become metamorphic rocks or to melt down to granite or any other magma. I am not altogether convinced of the truth of this. To take one local example, Professor O. T. Jones has shown that the thickness of sediment deposited in the British Lower Palaeozoic geosyncline is of the order of 45,000 feet. Everybody knows that the Lower Cambrian of North Wales is intensely cleaved, but not metamorphosed. However, the Leinster granite mass is 70 miles long and some 10 miles wide, a regular batholith, and there are very similar granites in the Isle of Man and at Skiddaw, along the same line of strike. Moreover it is now known that the Skiddaw slates are spotted for many miles to the south-west, far beyond even the generous aureole mapped by Ward. My suggestion is, then, assuming the doctrine of palingenesis, that these granites represent the melting of the base of this great geosyncline probably assisted by ascent from below, as long ago suggested by Ward. The granite fillings of the cores of other fold ranges may have arisen in the same way.

Another matter that commonly receives scant attention from petrologists in spite of its undoubted significance in the present connection is the curiously capricious distribution of ore deposits in connection with granites. The association of tin and tungsten with tourmaline granites is obvious enough, on the basis of volatile fluorides, given the presence of the tin and tungsten atoms, but what we do not understand is why this association is found in Western Europe only with the Hercynian granites, in the Malayan region with late Mesozoic, probably Cretaceous granites, and in Bolivia probably Tertiary. The long sequence of metalliferous zones around granite cupolas arranged on a descending temperature gradient, as in Cornwall, is also intelligible on the ground of physical chemistry, provided always the right elements are there. In Cornwall the two gold-silver zones happen to be missing and the series stops short of mercury, the lowest temperature ore, which is often deposited by hot springs in volcanic regions. The source of all these metals is unknown. They cannot come from the hypothetical sulphide-oxide zone below the sima, as then they would be associated with basalt, not granite, and tin always comes with acid rocks. Other elements of the same association are molybdenum and bismuth, and there is often much arsenic. The point of the whole matter, however, is not the mineral groups, but the fact that metallogenesis associated with granites is so sporadic and seems to show neither rhyme nor reason. This is a subject that I have studied deeply, but have never got any satisfaction out of it. There are also of course definite mineral associations with basic rocks, e.g. platinum and chromium with serpentines, but these need not be discussed here. The whole subject is, however, of great economic importance as a basis of scientific prospecting, and is well worthy of study.

From the innumerable subjects of interest raised by these three addresses only one more is selected for comment here: that is the theory of the derivation of granite magma from basalt; which seems to have a peculiarly

exasperating effect on Professor Read. My comment on this is that it would take a mighty lot of basalt to make the Main Range batholith of the Malay Peninsula, which is 300 miles long and 40 miles wide in Perak, and forms mountains up to 7,000 feet high. It is a curious point that tiny patches of the roof have survived on the tops of the two highest peaks of the country. There are several other large and parallel granite ranges, but the Main Range is selected because it is a very acid porphyritic rock with muscovite, biotite, and much tourmaline and tin, very like some of the Cornish granites. It would, therefore, on the theory of differentiation take the largest possible quantity of basalt to make it. According to Grout's calculation it needs twenty times this volume. Now frankly I do not see the need for all this fuss about differentiation. Everybody is agreed as to the existence of sial and sima, which must have separated once for all in the very earliest days of the earth's history, before there was any coherent crust at all. On this view granite and basalt were both differentiated from a common source, but that is not the same thing as differentiation of granite from basalt.

From an open-minded consideration of the whole subject of the origin of granite, as set forth in the writings here discussed, some fairly definite conclusions seem to arise.

Firstly, and probably the most important of all, it seems clear that one single explanation will not fit all cases : to quote A. H. Green's words, there are granites and granites. It would seem that at least three categories can be distinguished :—

(*a*) The enormous usually gneissose granitic masses of the Archaean shields and ancient continental blocks.

(*b*) What may be called the core-batholiths in folded ranges of the later revolutions.

(*c*) Minor granitic intrusions, including dykes, sills, and veins of any age.

(*a*) As regards the first category the room-problem arises in full force. If all these gigantic masses are regarded as strictly intrusive in whatever condition, that is, as added to the pre-existing rocks, the position is untenable. Apart from all evidence afforded by composition and structure, it is clear that they can only have been formed by alteration of pre-existing rocks, with little or no added bulk. But when all the other evidence, structural, mineralogical, and chemical, is taken into account the conclusion becomes irresistible : such granites never existed in anything that could be called a liquid form : in other words they were not formed by the intrusion and crystallization of a magma of the same composition. It may, of course, be said that this is obvious in the case of well-marked gneisses, but not all granites are gneissose. The answer is that there are so many transitional forms that the argument can be applied to all of them.

(*b*) The explanation of the emplacement of core-batholiths again involves the room problem. It may be suggested here that some confusion has been, as so often in other geological matters, caused by the drawing of sections with a much exaggerated vertical scale, seeming to imply an enormous amount of uplift. To refer again to a case already mentioned, in the Main Range batholith of Malaya, where the height of the roof is known, its slope works out at about 4°, and many others are no doubt

similar. It seems highly probable that such masses have been formed by the melting off or some other form of activation of the bottom of a geosyncline, leading to the usual kind of granitization, in spite of many suggestions that such a process is not known to occur. Here the ascent of the granitizing agents is probably helped by the folding.

(*c*) There still remains a large class of minor intrusions of granitic composition which do seem to be due to the actual injection of material as liquid into planes of weakness. With regard to dykes and veins there can be little doubt of this, but it has to be remembered that many of these injections were certainly specially rich in volatile constituents and remained liquid down to very low temperatures. The matter is more difficult with regard to granitic masses of an intermediate volume, smaller than batholiths but bigger than dykes and sills, such as laccoliths, if such exist. With these it is better to suspend judgment for the present. There are some very difficult cases, of which the Shap granite is a notable example.

At this point it may be well to add a few words as to what a magma is supposed to be. The extreme orthodox view seems to be that it is a liquid mainly composed of silicates, but with some volatile constituents, especially water, which help to keep it mobile. The more modern conception is, however, that a magma is more like a milky rice pudding, a sort of mash of crystals and liquid. This at any rate is the original meaning of the word. Now it is obviously difficult to apply the laws of solution, many of which only work for very dilute solutions, to a mass like this. But the point to be made here is that this kind of magma does not differ much from the current conception of migma. The weakest part, however, of the orthodox view of a magma is that nobody ever seems to suggest where it came from, and why it came at all.

When we try to envisage the real nature of the processes supposed to be responsible for the formation of granitic rocks, including gneisses, it would appear that the French theories really amount to metasomatism and pneumatolysis on a very large scale, without any implication of the intrusion of actual magma, and without any suggestion of complete fusion, whereas the Fennoskandian school seems to suggest some action by liquid magma in addition to fusion, though Sederholm once said later that what he meant was perhaps more like solution than fusion: in other words, a hydrothermal process. It may perhaps be suggested that the most modern conception of migmatization is to some extent a compromise between the two schools.

On an early page of this review it was said that Lyell's views would be mentioned again. That was because the last section of Granite II is headed " Return to Lyell " as a summary of the author's conclusions. Now Lyell's views had a strong French flavour, as was perhaps only natural, as he was well acquainted with many of the leading geologists of that country, and it is clear that he regarded granite formation and regional metamorphism as much the same thing. In fact he spoke of plutonic action as well as plutonic rocks. This matter is considered at some length in the Dundee address, and from this consideration Professor Read concludes that migmatization is the prime cause of regional metamorphism. As a comment on this I would add that in my far-off student days we were explicitly told that complete fusion was excluded from the

scope of metamorphism. This would have excluded the formation of granite by palingenesis from the metamorphic category, and yet it cannot be called intrusion, which was the current hall-mark of a plutonic rock. Hence orthodoxy is left on the horns of an uncomfortable dilemma. I doubt very much whether Lyell, the inventor of the word metamorphism, ever said, or thought, that fusion was excluded.

To sum up : from a dispassionate consideration of these three addresses and the quotations contained therein it seems that the orthodox conception of the origin of granite by intrusion and crystallization of a liquid magma, together with the accompanying view of the formation of gneisses by regional metamorphism of the country rock without change of composition is inadequate, at least on the large scale, and especially in the Archaean basement. The processes here discussed, whatever they may be called, seem to offer a more satisfactory explanation, though intrusion of magma on a small scale is not to be excluded. The main difficulty would seem to lie in the nature of the ultimate cause of it all and in the explanation of recrudescences of plutonic activity in periods of diastrophism. The answer is perhaps to be found in the application to the sial of Joly's theory of the storing up of energy in the form of latent heat as the result of radioactive disintegration.

The Mineralogy of a Neolithic Terrace at Tura, Egypt

By N. M. Shukri

PROFESSOR M. Amer, Vice-Rector of the Farouk I University, kindly introduced the writer to the interesting Neolithic site at Maadi (1, 4, and 5) and to similar deposits situated further to the south at Tura. The following note records the minerals present in the southern formation, which proved to be derived from the same sources as those contributing material to the recent Nile deposits at its present bank east of Tura. The investigation showed also that the relative amounts of suspended matter carried by various tributaries of ancient rivers could be determined by examining the relative abundance of the heavy minerals along their courses.

Good exposures of the Neolithic formation are seen in an abandoned railway cutting east of Cozzika railway station, between Tura el-Asmant and Tura el-Balad, on the Cairo-Helwan railway. The deposit, lying between the 30- and the 50-metre contour lines, rests directly upon Middle Eocene limestones and consists of irregular and lenticular beds of alternating sands and clays ; the sandy beds are current bedded and show the same characters as those found in the recent cliffs along the Nile banks.

The sandy and muddy samples of the Neolithic formation and of the more recent deposits (east of Tura) were deflocculated, when necessary, fractionated, and the fractions coarser than 20μ were separated by bromoform into light and heavy " crops " (using the centrifuge for the finer fractions) and were subsequently examined microscopically.

The minerals recorded (which reveal the presence of the same varieties in the same relative abundance in the ancient and more recent deposits and denote accordingly their derivation from the same source-rocks) are : quartz, orthoclase, microcline, plagioclase-felspars, iron-ores (magnetite, ilmenite, haematite, limonite), micas (muscovite and biotite), pyroxenes (yellowish augite, violet-brown titaniferous augite, diopside, diallage, hypersthene, enstatite, diopside-aegirite and aegirite), amphiboles (brown, green, and bluish-green hornblende and actinolite), chlorite, epidotes (pistachite, zoisite, and clinozoisite), garnet (various colours), tourmaline (various colours), staurolite, sphene, kyanite, apatite, rutile, olivine, monazite, andalusite (colourless and pleochroic), calcite (including *Nummulites*, etc.), gypsum, topaz, fluorite, ? sillimanite, and rock fragments, including a basalt or dolerite and a hornblende gneiss.[1] Apparently, the minerals recorded, comprising very unstable species in a remarkable state of freshness, do not show any sign of elimination during transportation, in spite of the long distances they have travelled.

[1] The iron-ores, micas, pyroxenes, and amphiboles, occurring in a decreasing order of abundance and in a very fresh state, are the main heavy minerals present, forming more than 90 per cent of the whole heavy minerals. Such an assemblage of minerals resembles that of the Red Sea bottom-deposits, both being remarkable examples for the richness of recent sediments (derived from crystalline rocks) in vulnerable minerals, notwithstanding the difference in their mode of formation (6).

Unstable minerals are present in a fresh and unetched state in grains less than 20μ in diameter.

Awad states (2, p. 287) that the most important feature in the creation of the Nile was the elevation of the Abyssinian Plateau, which occurred at different stages towards the close of the Mesozoic and continued perhaps to the end of the Tertiary. He further states (*op. cit.*) that the vigorous Abyssinian streams were thus able to tap and to capture the waters of the equatorial system and that " although we all consider the main river Nile as extending to the Mediterranean from beyond the Equatorial Lakes, and that its sources lay in that region, it is well to bear in mind that these so-called sources have been but a subsequent addition to the river, long after it had come into existence ". The mineral evidence suggests that the capture must have taken place earlier than the Neolithic. A more precise determination of the date is, however, under investigation.

It is interesting to note here that augite (yellow and violet-brown), which is very abundant in the two formations, is derived from the Abyssinian Volcanic Plateau, because samples south of Khartoum are devoid of these two varieties, whereas sediments from Wad Medani on the Blue Nile and from Khartoum itself from the Blue Nile side (at its confluence with the White Nile) contain the same varieties of augite in great abundance. The sediments south of Khartoum contain, in great abundance, the heavy minerals occurring in minor quantities further to the north such as epidote, staurolite, etc.[1]

It is also interesting to note that the heavy minerals near Cairo resemble those at Wad Medani on the Blue Nile, except that they are diluted with small amounts of the heavy minerals derived from the south. This is in harmony with the fact that the Blue Nile and the Atbara, both having their sources in the Abyssinian Plateau, contributed and are still contributing most of the material at Cairo.[2] It is for this reason that the Blue Nile has been able to impart the characteristic heavy minerals of its sediments to those near Cairo. Examining thus the heavy minerals of the sediments north and south of Khartoum and of the Blue Nile one reaches the conclusion that the greater part of the sediments north of Khartoum are derived from material carried by the Blue Nile without knowing this fact beforehand. This may be used in determining the relative amounts of suspended matter carried by various tributaries of ancient rivers by examining the relative abundance of the heavy minerals along their courses.

In conclusion, the similarity of the minerals (both in variety and abundance) of the newer and older formations does not only prove that both were derived from the same source-rocks and that the " pre-

[1] Hornblende occurs in abundance in the sediments of both the Blue and White Niles.

[2] Ball states that the average estimated quantities of suspended matter of the Nile passing Cairo yearly amounts to nearly 57 million tons, of which more than 55 million tons pass during the four flood months (August to November) and less than 2 million tons during the remaining eight months of the year. The average daily quantities work out at about 452,000 tons for the flood months and about 6,500 tons for the remainder of the year (3, p. 126).

Cambrian " of the southern countries was already uncovered in Neolithic times (as shown by the recorded mineral types, especially the metamorphic minerals), but also that in Neolithic times the greater part of the Nile sediments were carried by tributaries draining the Abyssinian Plateau as is the case at the present day. Climatological conditions in the Abyssinian Plateau and in the Lake Plateau Region were, accordingly, similar to those at the present day. Again it was shown that the Blue Nile captured the waters of the equatorial system at least as early as pre-Neolithic time.

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Leicestershire Climate in Triassic Time

By W. W. Watts

MUCH has been written on the subject of the physical and climatal conditions under which the Trias was deposited. Mention may be made of the work of Goodchild, 1896; Mellard Reade; Bonney, 1900, 1902; Lomas, 1907; and Bosworth, 1912. Their papers show a general concensus of opinion that the deposit took place under continental and desert conditions in an extremely arid climate. An important discovery made in 1899 by Mr. R. F. Martin near Mountsorrel, further finds at that place and near to it, and revelations made later at Mountsorrel itself, all seemed to the writer to give decisive confirmation to this conclusion. But doubt has been thrown upon the validity of some of this evidence, and it will be well to re-examine it.

Terraced and grooved surfaces of granite under boulder-clay at Mountsorrel, and under glacial sands at Hawcliffe, were long mistaken for the work of glaciers. My work for several years on the buried Triassic landscape of Charnwood Forest, as well as the inspection of photographs and of specimens preserved at the quarries, had made me sceptical as to this explanation and, seeking a different one, in 1899 I asked Mr. R. F. Martin, chief proprietor of the quarries, whether the "surfaces" had ever been found under the Keuper Marl which covers the granite in some parts of the area. He thought that he had seen them, but, as he could not be quite certain, he kindly promised to watch the "unbaring" which was then taking place to extend quarrying at Hawcliffe and Nunckley. Later in that year a message came from him telling me that such an exposure had been found, and suggesting that I should inspect it as soon as possible. Needless to say this was at once done.

I visited the excavations under the guidance of Mr. Martin's son and confirmed that they disclosed "surfaces" similar to those already known at Mountsorrel and Hawcliffe, but buried under several feet of Keuper Marl, that being in turn covered with boulder-clay at Nunckley. The granite was undecomposed, terraced, grooved, smoothed, and polished, the polish appealing even more to the touch than to the eye, and at once suggested the action of wind-erosion. But a more striking discovery was made at Hawcliffe. This was a detached block of granite, over a cubic yard in size, which had evidently been recently removed during the unbaring. It was perfectly fresh and undecomposed and bore upon several of its sides signs of sand-blast work. These were fretted, ribbed (or "corded"), and highly glazed. The rock surfaces had evidently been rough and the sand-blast had left them ribbed or corded, but every rib was smoothed and brilliantly glazed. The glaze agreed with that described by Dr. Bather in other cases of wind-erosion, in resembling "varnishing" which gives a shine to a surface not quite smooth, rather than "polish" which flattens and smoothes away any irregularities.

There was unfortunately no evidence left as to whether the block had been taken out of marl or drift, and none of the men could remember or indeed had noticed the block in any way. It was shown and its significance explained to Mr. Martin (junior) who agreed that it was of

sufficient interest to be preserved whole at the office ; but by some mischance it found its way to the mill or the spoil-bank and was lost. But I had luckily detached a couple of chips exhibiting the glaze which, with specimens from the surface of the granite *in situ*, are now in the collection of the Geological Survey.

A note on the finds was read to the British Association at Dover, and Mr. Martin reprinted the short paper in full for the use of the quarries. At Dover and later I found that geologists familiar with wind action in deserts (in India and Africa) were not completely satisfied that the specimens taken from the main granite mass *in situ* were wind-cut, but might conceivably have resulted from rather exceptional erosion by sand in water. This is understandable for they had not, as I had, seen and still less *touched* the rock when uncovered. But everyone that I consulted, and to whom I showed the specimens, was perfectly convinced that absolutely nothing but sand-blast could possibly account for the fretting, polish, and glaze of the detached block.

Some time before 1933 Dr. F. Raw had found fretted and glazed rock at Lilleshall in circumstances from which he concluded that its aspect was due to wind-erosion in Pleistocene times. He read a paper at the meeting of the British Association at Leicester that year (see *Geol. Mag.*, lxxi, 1934, pp. 23 and 44) in which he claimed that the evidence given by my detached block must be separated from that given by the surface of the granite under the marl ; and he argued that the features of that block had, like his own example, been produced at this later date. This knocked away one of the three legs of the stool on which my argument for Triassic deserts rested, and left my conclusions less securely perched on the other two, the perfectly undecomposed, smoothed, and polished granite of the Mountsorrel area, and the characteristic ruggedness of the crags under, emerging or emerged from, their Triassic cover in the Forest itself.

I am still, however, quite convinced that my block must remain as a clinching nail in the argument, for that it really came out of the marl and not out of any later deposit seems to me to be conclusively proved by the following facts :—

1. It was a *large* block, over a yard across, while the local drift contains only much smaller ones, whereas many large blocks have been seen in the marl over the granite. One, at Mountsorrel, is figured by Strangways in his Memoir on Sheet 156, p. 10, for which his caption is " The large block of Granite depresses the marl upon which it rests as if it had fallen in when the marl was soft ". Dr. T. O. Bosworth is even more illuminating in his paper on " The Keuper Marls around Charnwood ", published by the Leicester Literary and Philosophical Society. After a reference to the case just mentioned he says (p. 45) : " At Mountsorrel some of these stones are very large—say 5 feet thick—and are seen as much as 8 feet or more above the rock floor, see fig. 30." This figure, from a photograph, shows a block about 3 feet long, in marl over granite at Cocklow Wood Quarry, Mountsorrel.

2. Bosworth goes on in the next paragraph : " Sometimes, e.g. at Mountsorrel and Croft, these stones are greatly *worn*, and are set in the Marl with the grooving or terracing parallel with the bedding, just as

though they had been wind-worn *in situ.*" The block shown in his fig. 30 has such a worn surface which, like the bedding of the Marl is " inclined away from the observer ".

3. Stone in and under the Marl is invariably *fresh* and undecomposed, and fit to be sent to the mill as good rock when any rotted rock would be at once rejected. In contrast, rock long exposed, or in or under glacial sands, boulder-clay, or the Keuper sandstone, is always altered and rotten. Bosworth gave particular care to this point and is able to say (p. 37) " in some places, for instance, at the south side of the big working at Mountsorrel, the bottom part of the drift is mainly made up of the scraps of the weathered rock ". " At the south end of the big quarry at Mountsorrel, in places where there is no Keuper covering, this intense weathering is seen." On page 38 he writes : " In marked contrast is the state of the same rocks beneath the Keuper Marl. For right up to their very surface these rocks are in sound condition. At Mountsorrel, Croft, . . . the best stone is that beneath the marl . . . and it is found profitable to remove a considerable overburden to obtain it." The remarkable film of glaze on my specimen, with its minerals perfectly fresh right up to the film, can only have been preserved if embedded in a perfectly waterproof material.

Therefore I feel bound to urge that there is ample evidence that my block really came out of the Marl and its evidence can be added confidently to the rest that has been gathered to prove that desert winds were sand-blasting the rocks about Mountsorrel in Keuper time, and that there is valuable and indisputable evidence of desert conditions and a desert climate at this time in this part of England. Bosworth has given a rich store of other evidence in the paper from which I have so freely quoted.

On the Normal Faulting of Rift Valley Structures

By H. G. Busk

MUCH has recently been written about the compressional theory for the origin of Rift Valleys in Africa, and the supposed reversed faulting of their sides, and so little has been published about the evidence for their normal faulting, that those who have not had the opportunity of working in rift valley areas may possibly obtain a rather one-sided view of the problem. It seems fair, therefore, to ask for space in the *Geological Magazine* to reflect on the case against the compressional theory, and to bring forward in general some of the evidence in support of normal faulting.

A cause contributing to the controversy, if such it may be called, may be that in East and Central Africa, except along the coast, the rift faulting does not as a rule occur amongst easily mapped marine sediments with well-marked horizons, but either amongst volcanic rocks of great horizontal variability and lacking in easily distinguishable time horizons, or amongst the schists, gneisses, and igneous rocks of the Archaean Complex.

In contrast to this, on the western side of the Sinai Peninsula, the observer has before him a rift valley area, in which all the evidence stands out with startling clarity. The Upper Cretaceous and Tertiary rocks, of which much of the eastern side of the Gulf of Suez Valley is composed, are steady marine sediments, which show little variability through the length of the western coast of the peninsula, and in them are distributed lithological and fossil horizons, that can be identified anywhere with ease. The country is a desert, devoid of vegetation ; it is rough and mountainous, so that the evidence stands out both in plan and section, in what can only be described as a perfect joy to contemplate. But if the observer begins serious contour mapping, he will find that not only does each fault, if it is not vertical, dip away from its upthrow side at a steep angle, but that that angle can be accurately measured from the ground contours. Nor are double checks lacking. Many examples are present where the flat or gently dipping strata are crossed by steeply dipping igneous dykes, both becoming intersected by the same fault. The hade of the fault can be measured from the displacement of the dyke or from the displacement of the strata, and both will be found to agree after the manner of a block diagram in a textbook. Along the coast the Tertiaries are let down below sea level into the Gulf of Suez, and direct evidence of hade may be lacking. But, where each fault, for they are arranged *en echelon*, begins to die out,[1] its outcrop will be found to bend round into the cliffs and then inland, and from the contour map, which the observer will construct, the direction and angle of its hade can be measured with an assurance which is completely satisfying.

The faults, often of great throw, are as a rule clean cut, and, when compared with reversed faults in folded areas, have a surprisingly narrow brecciated zone ; there is often a monoclinal bend, upwards on the down-

[1] H. G. Busk, *Earth Flexures*, Camb. Univ. Press, 1929, p. 86.

throw side, and downwards on the upthrow side, and evidence of lateral compression is entirely absent.

The Peninsula of Sinai is an upthrow block, tilted to the north. At its southern end the aggregate throw of the faults letting down the rocks into the Gulf of Suez is more than 6,000 feet, and the whole stratigraphic column from the Palaeozoic to the Tertiary is represented.[1] The Gulf of Suez, though only an offshoot of the Red Sea, is none the less proved to be a rift valley of the first magnitude. Surely it is an area such as this that deserves the closest study, rather than one of those where lack of evidence leads us by default into theorizing which may mislead. It is but a small step from that stage, to fitting to our grand theories a few isolated facts which may be of only secondary importance.

But even in the Rift Valley Region of East Africa, where the marine sediments and the data they bring in, except along the coast, are absent, and the bush sadly obscures what evidence there is, there is enough in the writer's view to render the true nature of the faults incontrovertible. The form of the outcrop of the faults is the same as in Sinai. They are either straight or gently sinuous, or, if the upthrow blocks dip away from the fault, mildly crescentic in outline, the horn of each crescent marking the locality where each fault comes in or dies out. The sides of the Gregory Rift Valley are let down by faults *en echelon*, as is the case in the Gulf of Suez, and it only requires a short drive from Nairobi along Sclater's road to view these echeloned fault blocks magnificently displayed.[2]

The crescentic form of the outcrop of many of the faults may not of itself prove their normality, for crescentic forms are common enough in folded and reversed faulted regions, but their true nature becomes evident when we examine those localities where such faults come in or die out, the one behind the other, and note the absence of any parent fold to the supposed reversed fault, or if thrusting is suspected, any region of " roots ". In the Gregory Rift Valley, if you follow one of these faults along the strike to its origin, you will not find in any instance that the writer can recall, any suspicion of an overfold, or indeed any steep folding at all. The fault merely either peters out or may be replaced by a gentle monocline. There is, indeed, on a large scale, every gradation from the monocline to the rift fault. Bailey Willis has himself pointed out that the Mau escarpment in the neighbourhood of Nakuru is only " a gentle swell ", though it develops into a proper fault-scarp south of Eburu. Is it likely that reversed faulting can be present in such structural environment, without making its presence obvious, and that in no minor degree ?

Wayland's conception of an inverted wedge,[3] apex upwards, pressed down into the sima by lateral pressure, might seem at first sight rather attractive to the protagonists of normal faulting, for it is ingeniously arranged that all the evidence should be hidden by normal gravity faulting of the advancing and overhanging valley sides. But, even if such a pair of reversed fractures were to begin along parallel lines, in the manner

[1] *Op. cit.*, p. 97.

[2] Compare Degree Sheet " South A 37/gh ", Scale 1 : 125,000 Nairobi.

[3] E. Sherborn Hills, *Outlines of Structural Geology*, Methuen and Co., Ltd., 1940, p. 66.

of the bounding lines of the rift valleys, parallelism could not be maintained for long. Where resistance decreases near surface there would probably be a bending over of the faults to a lesser angle of dip ; the upthrow blocks would, in any case, approach each other to a greater or lesser degree, which would vary along the strike and, as the movement continued, unless the way is cleared between them by eroding agents, they would eventually rise the one over the other. In these later stages the origin of the movement could not fail to be exposed.

In South-Western Persia there can be found large scale models of this type of movement in plastic rocks, gypsum, limestone, and clays of the Lower Fars. The depressed wedge is here represented by a syncline of later and more rigid rocks. Opposed reversed fault scarps may be seen approaching one another, and cases of complete over-riding of the intervening syncline can be observed in profusion. Normal faulting in front of these structures is absent, and gravity slips in front of the moving scarps are low angle slides. It is worth noting that, in the same region, rift valleys on a small scale, with true normal faulting and clearly of tensional origin, are present, where the Asmari Limestone, underlying the Fars, is exposed. This occurs near the crest of the pitching ends of the limestone anticlines, and is of the " collapsed keystone " variety. The two types of faulting may thus be observed in the same region, thrust fault scarps and normal fault scarps.

Treading now upon more speculative ground we may note that in the folded regions of the earth volcanic phenomena are not often contemporaneous with the date of the actual folding, though they may occur afterwards. Folding, reversed faulting, rock sheets, and allied structures are comparatively shallow seated, and do not, apparently, originate much below the sedimentaries of the geosynclines ; but the volcanic phenomena of the rift valleys of Africa and their extensions into Europe are contemporaneous with the movements, which are thus probably very deep seated in origin.

It is difficult to follow Dr. Kent's contention in speaking of the Gregory Rift that " faulting has repeatedly terminated periods of volcanic extrusion ".[1] In the Gregory Rift Valley the older eruptive rocks have, of course, been faulted, but it would be difficult to prove that other eruptions were not occurring elsewhere in the valley, while the faulting was in progress. Whatever evidence there is, is in favour of this. It is hardly fair to state that " Upper Pleistocene and recent vulcanicity has been confined to the building of relatively small volcanoes which diversify the rift valley floor ",[2] when the trifle Kilimanjaro is still steaming. As for the valley floor itself the great mass of Suswa rises from it and overtops its sides, and Longonot is little lower. Kippipiri and Eburu lie banked against the Aberdare and Mau escarpments respectively, the latter with its active steam vents high enough to obliterate the rift valley wall. As for the eastern rift, the large and very active area of Mufumburu must compensate in some degree for the comparative quietude of the rest of this branch.

[1] P. Kent, The Age and Tertiary Relationships of the East African Volcanic Rocks. *Geol. Mag.*, lxxxi, 1944, p. 23.
[2] *Op. cit.*, p. 20.

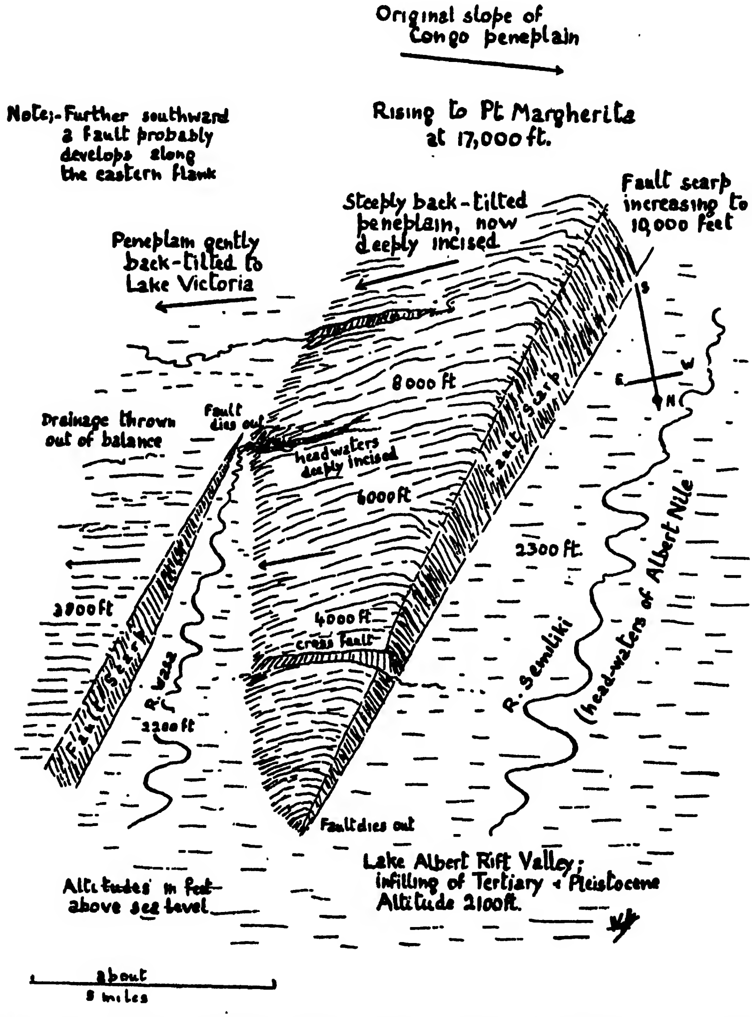
In the Gregory Rift Valley there is some justification for assuming that the amount of material extruded is a measure of the mass displacement of the downthrown region. Now it can be calculated that if the material extruded in and around the Gregory Rift Valley, including the great mountains of Kenya and Kilimanjaro and their lesser outlying satellites, were shovelled into the Rift Valley, this feature would be roughly filled up. Granting the near correctness of our assumption this means that the walls of the valley are nearly vertical, for if they are reversed and hade away from each other the material displaced as the floor of the valley fell would be much larger. If the faults are normal, but not vertical, and hade towards each other the material displaced would be less. In short, for rift valleys in general, if there are deep-seated reversed faults we should expect to find the material extruded greater than would be required to fill up the valley. If the faults are normal, the greater the hade the less the quantity of extruded material. Are there any rift valleys in existence where the former condition, i.e. where the extruded material exceeds that required to fill the valley, prevails ?

Many arguments in favour of the reversed fault theory are derived from field observations of thrusting on a very minor scale, generally near the rift valley walls. These observations have mostly been made in Uganda or Western Kenya. It is, in fact, rather surprising that there are not more instances of such minor displacements for rift valley movements must often give rise to gravity slips near surface, or even to true reversed faulting, which might be expected to be the result of local compression as the downthrow blocks accommodate themselves to their new positions. If the faults of a rift valley hade towards one another, however slightly, there must be compression as the downthrow block descends. Compression stresses may occur as the result of torque if the rift valley is curved, or, as in the Kavirondo Gulf, where it lies at an angle to the main trend. Such local strains may account for the small thrust movements described in Dr. Kent's recent and interesting paper,[1] but such thrusts as he cites and maps are on such a small scale compared with the grand structures, which give rise to the rift valleys with which we are dealing, that to lay much weight upon their significance hardly seems justifiable. His displacements are measured in terms of a few feet, or at most of a few tens of feet.

Another point which is made by the supporters of the compression theory is that geophysical research has shown that the value of gravity inside the Gregory Rift Valley is below normal. The area is one of " levity ", and lateral pressure of the side walls, bounded by reversed faults, would be required to hold the valley floor down. But the gravimetric balance only measures the value of g for the particular spot on which it is placed, the calculations for " corrections " after the observation has been made, especially where the thickness and nature of the sediments underlying the instrument are little known, may be pure theory. The floor of the Gregory rift valley and others as well are generally covered by an unknown thickness of incompact ash, and sometimes by

[1] P. E. Kent, The Miocene beds of Kavirondo, Kenya. *Quart. Journ. Geol. Soc.*, c, 1944, p. 85.

the diatomite deposits of old lakes, a material whose specific gravity nears that of cork, both of unknown thickness. The material surrounding the instrument may thus often be of extreme lightness, and if there is



Text-fig. 1.—Mt. Ruwenzori; its northerly pitching end, showing the chief morphological ingredients in its construction, *i.e.* the fault scarps en echelon, and the mountain as a great tilted block. From sketches made in the field.

isostatic balance the total thickness of the light material comprising the sial will be measurably greater than that of the sial of the plateau on either side. Hence possibly the low value given by the instrument for the force *g*.

But it is interesting to consider what would be the effect near surface of the " levity " of a rift valley floor held down by reversed faults. Surely there would be upthrown " splinters " along the edges of the valley instead of the down-dropped " splinters " in echelon that are their main features. Instead of the gently warped or flat plateau edge along the outside of the valley, which is the rule, there would be a saw edge of upthrown blocks, each marking a temporary and local release of pressure by upward movement, the resultant effect would be a rugged series of hill ranges along the plateau bounding the rift valley sides. What instances are there anywhere of such upthrown splinters ? Surely all the geological evidence is that isostatic balance lags but a very little behind the formation of the structures.

Protagonists of the pressure theory also bring forward the case of the " horst " surrounded by faults, notably the great mountain mass of Ruwenzori. " Is it to be supposed," say they, " that the whole of the African continent has fallen away from this isolated mass and left it as a sole surviving reminder of the height of the original surface ? " But there is no reason to assume that a falling away from a general level is the only movement that has occurred, and geological observation, such as that in the case of Ruwenzori, postulates uplift as well as depression. But it is important to bear in mind that differential movements should be related only to masses which are in juxtaposition, and misconceptions may arise if such movements are referred to sea level as a base. Movements may be such that both the plateau edges of a rift valley, and the rift valley itself may be raised relatively to sea level, the plateau to a greater degree, and the valley floor to a less. In the Gregory Rift Valley it is remarkable that the differential movement along the sides is nearly the same, whether this be measured at Nakuru or just north of Lake Magadi, though the height of both valley sides and bottom above sea level at the latter place is lower by 3,000 feet. Also the rift valley movements were initiated upon a broad peneplain, and not upon a flat and level surface. There is multiple evidence from the reversed drainage lines that the basin of Lake Victoria was originally near the watershed of the continent, and that the lake area once stood considerably higher than the eastern edge of the west-going drainage of the eastern Congo Plateau. The relative altitude of Ruwenzori above the region of the Victoria basin was not so great as it is to-day, and the initiation of the upthrow of the Ruwenzori mass from the peneplain may date back into Jurassic times.

The great peneplain of the Northern Frontier Province of Kenya, which extends northwards and eastwards from the Tana River to Abyssinia and Jubuland, and which is drained by those rivers, and those that fall into the Lorian swamp, is broken in its north-east corner in the triangle El Wak, Mandera, Ramu, by many isolated horsts of limited area, and their associated rift valleys. There is evidence that the upraising of these horsts, now several hundred feet high, was initiated in Jurassic times.[1] We cannot conceive that the whole of this great peneplain, possibly one

[1] H. G. Busk, Notes on the Geology of the North-Eastern Extremity of the Northern Frontier Province, Kenya Colony. *Geol. Mag.*, lxxvi, 1939, p. 215.

of the most remarkable in existence, could have fallen away from these blocks for, if it had done so, it would have become flooded by the Cretaceous and later seas, or otherwise thrown out of balance. The horsts on the contrary have been gently raised throughout this period from the Jurassic onwards, and any theory to account for this movement could hardly bring forward compression, for there is no folding discernible beyond a slight rolling of the upraised Jurassic plateau a little further to the west. This plateau is of limestone, a material notoriously susceptible to pressure which, if this had occurred with any intensity, would certainly have been relieved by folding in the limestone.

In a magnificent section exposed along the southern side of the Gulf of Aden, Barrington Brown,[1] working down the 49th Meridian, shows some 6,000 feet of beds ranging from Jurassic to Eocene, exposed in a series of fault scarps. Upon the plateau above the scarps he shows certain elliptical basins or synclines of small amplitude occurring in Eocene limestones. These limestones are underlain by a bed of anhydrite some 200 feet thick. He inclines to the view that these basins are collapse structures originating from a change of volume when the original gypsum became dehydrated, or alternatively from partial removal of the beds in solution. He does not consider that these structures are the result of regional movement. But it seems to the present writer that the mobility of gypsum or anhydrite under a light load is quite sufficient to explain them. Under greater load, and with sufficient thickness of gypsum, we should get plug extrusion. Indeed the stage is here set ready for the compressional theorists, but the chief actor never appeared. For had compression occurred, however light a reflection of that supposed to have acted at depth, there would have been a *decollement* or unsticking of the strata above the mobile anhydrite bed, and we should have had the folding, thrust fault scarps, and allied structural forms that are so well known to workers in the Fars Series of South-Western Persia.

Gregory inclined to the view that in the Rift Valley generally faulting was subsequent to uplift; that there was first up-arching and later faulting by collapse along the summit of the arch.[2] Bailey Willis [3] has shown that the absence of wind gaps across the fault scarps, which would have been left by the beheaded drainage lines, precludes this idea, and this evidence indeed appears to be final. But the present writer believes that uplift and rift faulting were contemporaneous, and were in action together over long periods. There never was an unbroken original arch nor incised drainage lines across the direction of the present scarps.

It is worth while noting how quiet have been the conditions during the process of marine sedimentation near the present coast. The stratigraphy of the east coast of Africa gives us a kind of small size pocket edition of the geological systems, and few pages are missing. Barrington Brown records a thickness of 6,000 feet between the Jurassic and Upper

[1] C. Barrington Brown, The Geology of North-Eastern British Somaliland, *Quart. Journ. Geol. Soc.*, lxxxvii, 1931, p. 259.

[2] J. W. Gregory, *The Rift Valleys and Geology of East Africa*, 1921. Seeley Service and Co., Ltd.

[3] Bailey Willis, East African Plateaus and Rift Valleys, 1936. *Carnegie Inst. of Washington.*

Eocene, south of the Gulf of Aden, a trifle when compared with the thickness of the sediments of a like age in the great geosynclines. In South-West Persia the Pliocene alone may be over 15,000 feet thick. In Tanganyika the geological column from Lower Jurassic to Miocene is contained within 2,000 feet of strata, and future workers may one day find every well-known fossil zone represented. Throughout this period the continent must have been here nearly at rest. But slow movements, consonant with these quiet conditions, were in some places in action at a quite early date. South of Abyssinia, in the Northern Frontier Province of Kenya near the borders of Jubuland, there is evidence that here the very earliest movements date from the Jurassic. Here the present upraised horsts may have been low islands in the Jurassic Sea. Similar evidence is available in the more easily accessible Mombasa District, where the old Jurassic shore-line, indented round the existing horsts, can be traced.

Thus the present geological evidence indicates quiet; an era of immobility, followed by gentle movements, spun out over long ages. Volcanic activity was probably equally spun out, but may have been initiated later than the first of the movements.

With the record of such a geological history it is difficult to see how the compression theory for rift valleys ever arose. It does not seem to have occurred to Gregory. Is it possibly the result of an urge to search for difficulties by those observers who do not like being surrounded by a grand plan of sublime simplicity? By a mere flight of steps we can descend from the simplicity that rules the major faulting of the valley sides, to the beautiful and unchallenged perfection of the normal faulting of "Sikes's Grid", in the floor of the Rift Valley itself in the Magadi District, or, as the writer often thinks of it, The Country of Gregory's Railway Platforms.

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W.C. 1.

ANNOUNCEMENT

CLOUGH MEMORIAL RESEARCH FUND

This fund was instituted in 1935, for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Durham, Cumberland, Westmorland, and Yorkshire. Under the terms of administration of the Fund a sum of approximately £30 is available annually.

Applications for grants are invited for the period 1st April, 1945, to 31st March, 1946. These applications should state (1) the nature of the research to be undertaken; (2) the amount of grant desired; (3) the specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in field, excavation of critical sections, etc.; (4) whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Memorial Research Fund Committee, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st March, 1945.

REVIEWS

FOUNDATIONS OF PLANT GEOGRAPHY. By STANLEY A. CAIN. 556 pages. Harper and Brothers, New York and London. Price $5.

A surprisingly large part, nearly a third, of this book deals with Tertiary climates, and as it contains many unfamiliar ideas, it is to be taken seriously by geologists whose work touches on this subject. Its title is fair—it lays foundations; it does not try to build an edifice of fact or only sketches it incidentally. The method is to survey the numerous factors which interact to determine where a plant grows, and then to illustrate these factors by taking a single example at considerable length. This geological part will alone be considered here.

The author is a Botanist concerned with living North American plants; he is not a Fossil Botanist but is in close touch with the progress of Fossil Botany and willing to express his own views. He holds that changes in plant distribution occurred in a big way through big causes, and the chief cause is climatic change. Not only did particular species chase their favoured climates across the face of the globe, but the whole flora of which they were members maintains its composition. Thus he tells us that a Botanist would see very little difference if he could step from a present Californian Redwood forest into a Miocene Oregon forest; both major and subsidiary species of the floras being largely similar.

This brings us to a central theme "Paleoecology", the study of ancient plant communities. The Geologist may not realize how troublesome is the whole business of plant communities. Some Botanists see a type of vegetation—say heather moor or beech forest, repeated in numerous patches and to them these are real plant communities, even comparable with species. Others point out that no two patches are the same, nor even is one homogeneous and regard the community as an abstraction derived by neglecting awkward cases, commonly useful but sometimes misleading. Most of us wobble between these extremes, but the Americans, dealing with vast areas of undisturbed vegetation, take communities more seriously than we do.

The material of the "Paleo-ecologist" is simply a large number of fossil leaves or seeds: he gets his evidence from:—

1. Specific, generic, or family determinations.
2. Relative frequency of different species.
3. General type, irrespective of determination, e.g. tiny heather-like leaves; large laurel-like leaves, and so on. It is safe to say that everyone who has worked much on Tertiary plants believes that he can place them in their proper genera, and these are nearly all recent ones.

Many who have scarcely studied them at all (including the reviewer) feel misgivings, but are restrained from making public protest by the thought that they ought first to do a lot of work. Let us then accept that plants are now almost the same as in the Middle or even older Tertiary and that a Botanist who has looked at pressed leaves for some years can spot a genus from a fossil leaf rightly as a rule. It is at least clear that Tertiary Fossil Botanists have wide knowledge of the world's flora and that the jibe that all fossil plants belonged to Botanic Garden genera is no longer fair.

Paleoecology is on dangerous ground when it is used as a guide to determination, its own basis. Suppose a birch-like leaf was found in a flora whose other genera were tropical American, we can do our best with it and leave its name as an ugly blot on the list, but instead we are recommended to look very hard at the Central American flora and find an alternative plant there which matches as well : the list is now perfect. Of course everyone does look hard at a discordant bit of evidence, but this process, unless open, could easily convert a few errors into a most frightful racket.

As most of the recent work on Tertiary plants has been American it is useful to have a book which summarizes American views and aims : European work is, however, included. Unfortunately the tabulated style, each sentence like a Euclidian proposition, makes heavy reading and Paleoecology is born carrying the load of special terms of the ordinary Ecologist. The very sentences are often difficult, though the thought is clear when you get there. On the other hand it is an optimistic and pioneering work.

T. M. H.

PRINCIPLES OF PHYSICAL GEOLOGY. By ARTHUR HOLMES. Pp. 1–532, with 95 plates and 262 text illustrations. Thomas Nelson and Sons, Ltd., 1944. Price 30*s*.

We must congratulate Professor Holmes on giving us a book so clearly written and beautifully illustrated, and the publishers on producing the good paper, print, and reproductions far superior to the majority of books published during war-time.

Professor Holmes divides the book into three parts ; in many respects, however, it is felt that it might with advantage have been divided into two books. Parts I and II form an ideal elementary textbook with superb illustrations and thoroughly up to date in its information. These parts follow, in the main, the classical lines of textbooks dealing with Physical Geology, stressing that the object of Physical Geology is to help in the reconstruction of the past while Physical Geography is more concerned with the interpretation and classification of the present. These two parts are refreshing in that they contain many new examples drawn from Britain and overseas. Not only do they have new examples, but new features are introduced, such as the problem of submarine canyons, and although Daly's theory of their origin is clearly favoured a caveat is entered regarding the erosion of solid resistant rocks.

The chapter on glaciers and glaciation follows the orthodox views more than any. For instance, the want of grade in upland glaciated valleys is attributed solely to glacial erosion on the well-known lines of W. M. Davis's work, and the role of protection and initial breaks of grade are barely mentioned. At the end of this chapter it is perhaps a pity that (fig. 133) the climate in the great interglacial is stated to be "cool" and in the last interglacial to have been "warm". On the whole recent research does not appear to be in accord with these views.

In chapters xv and xvi we have Life as a Rock Builder and Life as a Fuel Maker, both of them very useful chapters not found in many

books. Professor Holmes ends these chapters on a more optimistic note regarding potential oil resources of the world than is found in many publications.

Part III begins at p. 358, and from there on to the end of the work (p. 509) the chapters tend to become more detailed in their contents and more speculative in their nature, ending up with the problems of continental drift. Many will feel that much of this part is more suitable for rather more advanced students who have developed a capacity to read critically and who are able to distinguish between attractive theory and fact.

It is certainly not suggested that Part III should not have been written, but whereas Parts I and II can be wholeheartedly recommended as a textbook to every elementary student of geology it may be felt that a beginner may be led away by Professor Holmes's clear and attractive presentation and fail to notice that he does not claim that all the opinions expressed in this part are of the same proved or accepted value as the old-established views given in the earlier parts.

Nevertheless Part III contains an extremely useful summary of many modern views and theories of the internal structure of the earth and more mature students will turn to this with advantage.

There is only one "fly in the ointment": the price is 30*s*.

W. B. R. K.

GEOLOGY OF THE CRETACEOUS (GUALALA GROUP) AND TERTIARY FORMATIONS ALONG THE PACIFIC COAST BETWEEN POINT ARENA AND FORT ROSS, CALIFORNIA. By CHARLES E. WEAVER. *University of Washington Publications in Geology*, vol. 6, no. 1, pp. 1–29. July, 1944. Price $1.15.

This memoir deals with a down-faulted strip of the Pacific Coast, about 40 miles long and from one to five miles wide, on the downthrow side of the San Andreas Fault—a fault still growing, as shown by the earthquake of 1906. The area stretches about 60 to 100 miles N.W. of San Francisco; the coast consists of rugged cliffs averaging 50 feet in height, but inland the covering of dense forest and deep soil makes mapping difficult, and there are Pleistocene terrace-gravels concealing the solid geology. Professor Weaver, nevertheless, presents us with a series of maps on nearly a 6 in. scale (1,000 feet to the inch), mainly of the actual coast and probable under-sea extensions, with scattered inland outcrops. There are a number of sections, drawn to the true scale of the map, showing high dips and very sharp folds.

The rocks on the upthrow side of the fault belong to the Franciscan Group (Jurassic or Cretaceous). The down-faulted strip consists mainly of very high Cretaceous sediments, the Gualala group, which at one point are seen to rest unconformably on a diabase, probably of Franciscan age.

At the north-western end of the area Tertiary beds come in, with a basal basalt unconformable to the Cretaceous. There are three divisions in ascending order—Skooner Gulch (350 feet, arenaceous), Gallaway

(1,218 ft., sandstone and shale), and Point Arena (3,115 feet, sandstone and shale). The two latter formations have yielded a considerable fauna of foraminifera, 130 species in all. This is compared to faunas from Ecuador and Venezuela, and is referred to the Miocene period. It is suggested that the unfossiliferous Skooner Gulch formation may be Oligocene.

A. M. D.

CORRESPONDENCE

THE AGE AND TECTONIC RELATIONSHIPS OF EAST AFRICAN VOLCANIC ROCKS

SIRS,—Dr. Pulfrey has made some useful corrections and additions in his letter (*Geol. Mag.*, lxxxi, 1944, 191–2) commenting on my paper on East African Volcanic rocks (*Geol. Mag.*, lxxxi, 1944, 15–27), but one or two points require further mention.

The question of the correlation of the phonolites of the Kisumu and Nairobi districts was briefly discussed in the paper (*loc. cit.*, p. 19). There is at each locality evidence of considerable age, so that Gregory suggested in each case that the flows might be Upper Cretaceous, and Sikes emphasized that the phonolites of the Nairobi district had been denuded before the later (partly Pleistocene) flows were extruded. In the intermediate area of Tindaret, which is on the edge of the main rift valley volcanic area opposite to Nairobi, there is strong indirect evidence that the phonolite is post-early Miocene. It would be expected that accumulations of similar lavas would be practically contemporaneous on opposite sides of the same lava field, and hence that the Nairobi Phonolites are late Lower Miocene or early Middle Miocene, as are those of Tindaret and a large part of the flows of the Kisumu region.

The occurrence of phonolite above as well as below the Lower Miocene basalts at Elgon agrees with the succession of Lake Rudolf and Nairobi (*loc. cit.*, p. 24), and Dr. Pulfrey's work indicates a somewhat similar state at Uyoma. It would be unwise, however, to assume precise contemporaneity between these various beds, and as Dr. Pulfrey suggests there may be much more alternation of types than has yet been recognized.

The identity of the N.E.–S.W. Lambwe fault with the East–West southern rift fault seems somewhat questionable to the writer. The boundary fault of the rift appears to die out as it approaches Kendu, and there seems to be no evidence of any important fault in the fifteen miles between there and Homa Bay. The Lambwe fault appears as a medium-sized displacement south of Homa Bay, and increases south-westwards. The two breaks may be genetically connected, but the writer is inclined to regard Lambwe the easternmost member of an independent group of N.E.–S.W. fractures (*Geogr. Journ.*, c. 1942, p. 26). Confirmation that the northern fault continues westwards through Asembo as a belt of shearing is, however, of considerable interest and importance.

P. E. KENT.

HAMBLEDEN MILL,
BUCKS.

GEOLOGICAL MAGAZINE

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Sapphirine from Dangin, Western Australia

By REX T. PRIDER (Department of Geology, University of Western Australia)

WHILE examining some vermiculite deposits at Dangin in 1940, on behalf of Messrs. Brisbane Wunderlich Co., Ltd., some rather friable gneissic to schistose rocks associated with one of the vermiculite occurrences were seen to contain an appreciable amount of a pale bluish mineral which from its optical properties was determined as sapphirine. As this was the first record of sapphirine from Western Australia, the mineral was separated and later chemically analysed at the Government Chemical Laboratory. Descriptions of the occurrence, characteristics, and genesis of this sapphirine and the associated rocks are set out in this paper.

THE OCCURRENCE OF SAPPHIRINE-BEARING ROCKS

Dangin, which is situated on the York–Bruce Rock railway, approximately 90 miles due east from Perth, lies in an area of Pre-Cambrian rocks, which are mainly granitic gneisses containing lenticular xenoliths of more basic rocks. This type of country extends in an easterly direction from York, and the geology is strikingly reflected in the soil coloration—the location of the basic xenoliths being represented by a reddish-brown soil occurring as patches up to several chains or more in diameter surrounded by lighter-coloured soil derived from the more acidic granite gneiss country rocks. Several miles west of Dangin unweathered examples of the basic xenoliths are exposed in a small railway cutting and are seen to be ultrabasic hornblende-hypersthenites (of charnockitic affinity) with which are associated garnetiferous cordierite-hypersthene rocks, biotite (vermiculite) schists, and hypersthene-bearing granitic gneisses. These rocks, some of which very closely resemble the charnockites of Madras, are the subject of a paper at present in course of preparation.

The sapphirine-bearing rocks come from a well about 20 feet deep situated near the southern boundary of Loc. 10052, a few chains west from the north-west corner of Loc. 20574 (see W.A. Govt. Litho 3/80) close to the Dangin railway siding. There are no rock exposures at the surface in the immediate vicinity, the soil being very light in colour which would normally be interpreted as indicating that the underlying rock is granitic. The well, which is approximately 20 feet deep with short drives several yards long to the east and west at the bottom, exposes a narrow lenticular band of mica schist between layers of a schistose to gneissose lighter-coloured biotite-felspar rock. The strike of these rocks is approximately east and west and the dip is very steep to the south.

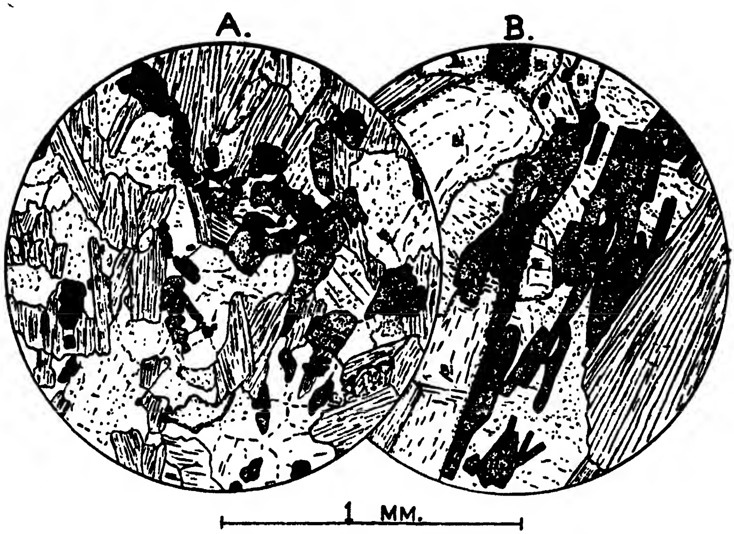
PETROGRAPHY

(*a*) *The Mica Schist*.—This rock, forming steeply-dipping layers up to 3 feet wide in the more granitic country, is made up almost entirely of deep-coloured biotite which in hand-specimen varies from black to bronze in colour. The structure is schistose and the mica plates average from 1 to 2 mm. in diameter. The bronze-coloured mica possesses the properties of a vermiculite, since it exfoliates markedly on heating, but the deeper-coloured varieties do not exfoliate. This property of exfoliation appears to depend on the state of weathering reached by the mica, since examination shows that both types have the same optical properties (practically uniaxial, $\beta = 1{\cdot}603 \pm {\cdot}002$) except that the bronze-coloured exfoliating variety has, when viewed in transmitted light, a deeper brownish colour and more turbid appearance than the clear non-exfoliating variety. Samples of both these mica schists were crushed and the mica panned off and it was noted that the residues from the two specimens were very unlike in character. That from the darker-coloured specimen consisting largely of blue sapphirine with occasional small zonally structured zircons, while the residue from the bronze-coloured exfoliating mica consisted entirely of pale purple zoned zircons: sapphirine was entirely absent.

The dark-coloured sapphirine-bearing schist is composed almost entirely of greenish-brown biotite with occasional small lenticles to 5 mm. × 1 mm., consisting of an aggregate of microperthitic orthoclase and sapphirine (Text-fig. 1B). These small lenses are elongated parallel to the schistosity, and contain an abundance of sapphirine in long prisms which are also arranged parallel to the schistosity (Text-fig. 1B). The microperthitic felspar forms an aggregate in which the perthitic structure is arranged approximately at right angles to the schistosity. No sapphirine occurs outside these small lenses, and it is evident that sapphirine and microperthitic felspar are closely related in their development.

(*b*) *Sapphirine-biotite-felspar Schist*.—This is a light-coloured, very friable rock with a schistose to gneissose structure. It contains small lenticular areas of biotite schist (similar to (*a*) above), and a noticeable feature is the tendency of the blue sapphirine to be concentrated into small lenticular areas or streaks parallel to the schistosity, but there is also a sporadic occurrence of small sapphirine grains throughout the whole rock. By separation and weighing the sapphirine was found to make up 4·5 per cent dry-weight of the rock. The other constituent minerals are biotite, microperthitic orthoclase, and plagioclase, with smaller amounts of accessory zircon and corundum. The relationships of the main constituents are illustrated in Text-fig. 1A. The texture as seen under the microscope is schistose to granoblastic. Felspars are the most abundant of the minerals present and these consist predominantly of microperthitic orthoclase with minor amounts of plagioclase (Ab_7An_3). The felspars are in granoblastic aggregates, and in spite of the friable weathered appearance of the hand-specimen are fresh and unaltered. The mica is a greenish-brown almost uniaxial biotite similar to that in the mica schists, and has X pale yellow $<$ Y = Z greenish-brown, and contains strongly-pleochroic haloes about zircon inclusions. Although the biotite is generally in flakes with the basal surfaces well developed

it sometimes forms aggregates with a contorted structure and in such cases it has lost a great deal of its strong absorption. Associated with these contorted aggregates is a pale yellowish isotropic mineral which appears to be pinite after cordierite. Sapphirine is fairly abundant in irregularly-cracked prisms of variable shape generally elongated in the direction of schistosity and contains a little iron oxide alteration product along the cleavages. From this rock a sample of sapphirine (pure except for a very small amount of iron oxide coating internal fractures and very rare grains of corundum) was separated for analysis.



TEXT-FIG. 1.—A. Sapphirine-biotite-felspar schist showing tendency of highly refracting sapphirine to be oriented parallel to the mica flakes. The microperthitic orthoclase is in equidimensional anhedral grains.

B. Sapphirine-felspar lens in biotite schist, showing prismatic habit of sapphirine. The microperthitic orthoclase is granular anhedral and the perthitic structure is approximately normal to the schistosity. Biotite flakes lying parallel to the section and thus showing no cleavage are marked Bi.

The sapphirine has the following characteristics: no cleavage, bright blue in colour, and strongly pleochroic with X pale yellowish-green to colourless, Y blue, Z deep blue, absorption $X < Y < Z$. The prisms have positive elongation and $Z \wedge c = 7°$. It is biaxial, optically negative, with optic axial angle approximately 50°. Dispersion $r < v$ of the optic axes is strong. In the acute bisectrix figure the isogyres are both fringed with blue on the convex and yellow on the concave side so that the nature of the dispersion of the bisectrices is obscure. The dispersion is symmetrical with respect to the optic plane so that any dispersion of the bisectrices is therefore inclined. The refractive index $\beta = 1{\cdot}720 \pm {\cdot}002$. Birefringence is weak and sections normal to Bx_a show anomalous purple-blue interference colours. The specific gravity is $3{\cdot}554$ at 22° C. The chemical

analysis of this mineral is set down in Table I, col. 1. After removal of the small amounts of H_2O and Fe_2O_3, which are most probably due to the limonitic impurities on fracture surfaces, the analysis was recalculated to 100 per cent (col. 2), which yields the structural formula

$$(Mg, Fe, Al)_{1\cdot951}\ Al_{4\cdot000}\ (Si, Al)_{1\cdot000}\ O_{10}$$

This agrees very closely with the formula $Mg_2Al_4SiO_{10}$ suggested by Gossner and Mussgnug (1928).

TABLE I

ANALYSIS AND CALCULATION OF SAPPHIRINE FROM DANGIN, WESTERN AUSTRALIA (ANALYST, J. D. HAYTON)

	I.	*II.*	*Mol. Prop.*	*No. of metal atoms on basis of* 10(O)		
SiO_2 .	14·89	15·26	·2541	·900		1·000
P_2O_5 .	0·10	0·10	·0007	·005		
					·095	
Al_2O_3 .	60·44	61·93	·6080	4·309	4·000	4·000
					·214	
TiO_2 .	0·04	0·04	·0005	·002		1·951
Fe_2O_3 .	1·70	—	—	—		
MgO .	15·23	15·61	·3870	1·372		
FeO .	6·45	6·61	·0920	·326		
MnO .	0·20	0·21	·0029	·010		
CaO .	Nil	—	—	—		
Na_2O .	0·21	0·22	·0035	·025		
K_2O .	0·02	0·02	·0002	—		
H_2O+ .	0·57*	—	—	—		
H_2O- .	0·41	—	—	—		
	100·26	100·00				

* By loss on ignition.

In the analysis the following were proved to be absent: CO_2, Cr_2O_3, ZrO_2, BeO. Spectroscopic analysis also proved absence of boron.

I. Sapphirine from sapphirine-biotite-felspar schist, Dangin, Western Australia.

II. Analysis *I* recalculated to 100 after removal of Fe_2O_3 and total H_2O.

GENESIS OF THE SAPPHIRINE

As has been noted the sapphirine finds its most extensive development in the more felspathic rocks, and when it occurs in the biotite schist it is confined to small lenticular areas where it is closely associated with microperthitic orthoclase. There is therefore a close relation between the formation of the orthoclase and sapphirine. Since all stages between the biotite schist and the sapphirine-biotite-felspar schist have been found, and because the granitic gneisses of this area contain abundant microperthitic felspar, it appears that the sapphirine-biotite-felspar schists have resulted from the felspathization of earlier schistose rocks by potassic solutions or emanations from the intrusive granite (gneiss). Certain seams have only been slightly felspathized and remain as mica schists.

The mica schists in their turn appear to have been derived from hypersthenites xenolithic in the intrusive granite (gneiss) such as are exposed several miles to the west of Dangin. At this locality the hypersthenite is traversed by a steeply-dipping layer of biotite schist, the biotite of which has marked exfoliating properties and similar optical characteristics to that in the sapphirine-bearing rocks. This biotite schist appears to result from the phlogopitization of the hypersthenite by potassic solutions or emanations from the intrusive granite (gneiss), a similar example of which has been described from the Toodyay District of Western Australia (Prider, 1940, p. 370). The Dangin hypersthenites, although not so rich in pleonaste as those from Toodyay (Prider, 1940), do nevertheless contain a little of this spinel, which with silica introduced from the intrusive granite (gneiss) would yield the sapphirine thus :—

$$\begin{array}{lcl} \text{Pleonaste} & + \text{ silica} & \rightarrow \text{sapphirine} \\ 2(\mathrm{Mg,Fe})\mathrm{Al_2O_4} & + \mathrm{SiO_2} & \rightarrow (\mathrm{Mg,Fe})_2\mathrm{Al_4SiO_{10}}. \end{array}$$

The genesis of the sapphirine-bearing rocks from Dangin may therefore be summarized thus : spinel-bearing hypersthenites (similar in origin to those of the Toodyay District) have been intruded under stress by a potassic granite magma which has led to (1) the alteration of hypersthene to biotite by addition of potash and alumina emanations from the magma ; (2) to a felspathization of the resultant biotite schist by felspathic material derived from the intrusive magma ; and (3) to the development of sapphirine from the original pleonaste by addition of silica from the intrusive granite.

Lacroix (1929) has shown that sapphirine is generally closely associated with spinel and that there are two distinct types of sapphirine : (i) that from the crystalline schists which is poor in iron, and (ii) an iron-rich variety occurring in eruptive rocks or basic eruptives which have assimilated aluminous sediments. The Dangin sapphirine is an iron-rich variety and belongs to the second type. It closely resembles the sapphirine from the Vizagapatam District of India, described by Walker and Collins (1907), both in its composition and the nature of the associated rocks. Walker and Collins consider that the ultrabasic spinel-bearing rocks of Vizagapatam are ultrabasic members of the charnockite series that have been contaminated by absorption of sillimanite schists (khondalites). At the contact of these ultrabasic charnockitic rocks and the khondalites there are rocks very rich in sapphirine which has developed at the expense of the spinel. With the absorption of more sillimanite schist into the charnockite there has been an increase in the amount of sapphirine developed. The ultrabasic charnockites of the Vizagapatam District are represented at Dangin by spinel-bearing hypersthenites similar to, although not so rich in spinel as those of the Toodyay District of Western Australia which are considered to be formed from an ultrabasic magma contaminated by aluminous sediments (Prider, 1940). The development of the sapphirine in the Dangin rocks may have been effected by the mechanism suggested by Walker and Collins (i.e. the absorption of increasing amounts of sillimanite schist into the charnockitic magma). The Dangin rocks differ from those of Vizagapatam in having been felspathized and the close association observed between microperthite and sapphirine in the Dangin rocks

suggests rather that the silica necessary for the conversion of spinel to sapphirine may have been derived from the granitic magma which has been responsible for the felspathization of the spinel-bearing biotite schist—a rock which was itself originally a spinel-bearing hypersthenite.

ACKNOWLEDGMENTS

The author wishes to thank Messrs. Brisbane-Wunderlich, Ltd., for permission to publish this paper and also the Government Mineralogist and Analyst of Western Australia (Mr. H. Bowley), who arranged for the analysis of the sapphirine in the Government Chemical Laboratory.

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Revision of certain Lower Ordovician Faunas from Ireland

I. Trilobites

By F. R. C. Reed

SINCE the publication of the papers by Messrs. Gardiner and Reynolds on the Tourmakeady and Glensaul districts in the west of Ireland,[1] with palaeontological appendices by the present author, Raymond (1925, p. 167) has compared the faunas with those of Newfoundland and pointed out some striking resemblances. Other Lower Ordovician faunas have since then been described from various foreign regions, and in the light of this increased knowledge the specimens in the collections from Ireland have been re-examined; this has resulted in revised generic identifications, though confirming the reference of the beds to the Lower Ordovician as the author originally maintained (1910, p. 271). The trilobites, several of which are now put in other genera, are mostly allied to or comparable with species of the Canadian and Ozarkian of North America, Newfoundland, and Greenland which Poulsen (1937, p. 72) correlates with the Arenig and Tremadoc, and they also show resemblances to some of those of the Ceratopyge fauna (Brögger, 1896) of Europe and Western North America (Raymond, 1922) as well as with those of Newfoundland. The brachiopods, the determination of which had been found a matter of much difficulty owing to their poor preservation, possess affinities with many of the American Upper Ozarkian and Canadian species recently named by Ulrich and Cooper (1938), especially with those from Canada, rather than with any of the European forms with which they were previously compared or identified. The admixture of Upper Cambrian fossils with those of the Ceratopyge zone, especially in Nevada and the Mount Robson district, was noted by Raymond (1922, p. 20); and similar interrelations of the two faunas are also traceable in the present case. From the general aspect of the faunas from the Irish localities, Ulrich (1930, p. 19) was inclined to put the beds "about the middle or upper Chazyan"; Grabau (1935, p. 101), relying on the lists of brachiopods and trilobites in the present author's original papers, would refer them to the Middle rather than the Lower Ordovician, but this view can no longer be held.

Revised List of Trilobites

	New Names.	*Old Names.*
Ts.	*Ectenonotus connemaricus* (Reed)	*Cybele connemarica* Reed (A 10382a, b). *Phacops* sp. (A 10427).
Gs. Ts.	*Ectenonotus octocostatus* Reed .	*Encrinurus* ? sp. (A 10415). *Encrinurus octocostatus* Reed (A 10416). *Pliomera pseudoarticulata* Portl. (A 10419).
Ts.	*Pliomerops shangortensis* sp.nov.	*Pliomera* aff. *barrandei* Billings (A 10391).

[1] *Quart. Journ. Geol. Soc.*, lxv, lxvi, 1909, 1910.

	New Names.	Old Names.
Ts.	*Pliomerops (Protopliomerops)* cf. *primigenus* (Ang.).	*Acidaspis* ? sp. (A 10380)
Gs.	*Pliomerops (Protopliomerops)* cf. *insolitus* (Poulsen).	*Pliomera pseudoarticulata* ? (A 10420).
Ts.	**Cybelopsis* ? sp. . . .	(A 10431).
Tc.	*Kawina divergens* sp. nov. . .	*Pliomera* aff. *fischeri* Eichw. (A 10396)
Gs.	**Kawina* cf. *vulcanus* (Billings) .	*Pliomera pseudoarticulata* ? (A 10421).
Gs.	*Bathyurellus glensaulensis* Reed	*Bathyurellus glensaulensis* Reed (A 10410–12).
Gc.	*Bathyurellus ornatus* sp. nov. .	*Niobe* sp. (A 10418a, b).
Ts.	**Hystricurus* cf. *tuberculatus* (Walcott).	*Cyphaspis* ? sp. (A 10430).
Gs.	*Bathyurus* ? *reynoldsi* sp. nov. .	*Bathyurus* aff. *timon* Billings (A 10414).
Gs.	*Petigurus* ? cf. *crassicornis* (Poulsen).	*Bathyurus* cf. *nero* Billings (A 10413).
Gc. Gs.	*Nileus armadillo* Dalman . .	*Nileus armadillo* Dalm. (A 10417a, b, A 10416).
Ts.	*Symphysurina* cf. *elegans* Poulsen	*Symphysurus* ? sp. (A 10397).
Tc.	*Illaenus weaveri* Reed . .	*Illaenus weaveri* Reed (A 10387, A 10316).
Tc. Ts.	**Illaenus* cf. *consimilis* Billings .	*Illaenus* cf. *chudleighensis* Holm (A 10385–6, A 10457).
Tc.	*Telephus hibernicus* Reed . .	*Telephus hibernicus* Reed (A 10398–9).

[All the above species except the four marked * were figured and described, but several under other generic or specific names (*op. cit.*, 1909, 1910), and some are redescribed below.]

Tc. = Calcareous Series, Tourmakeady.
Ts. = Shangort Series, Tourmakeady.
Gc. = Calcareous Series, Glensaul.
Gs. = Shangort Series, Glensaul.

The registration numbers refer to the specimens in the Sedgwick Museum.

The few small fragments of trilobites which were given in the list of species from Tourmakeady as *Harpes* sp., *Calymene* sp., *Cheirurus* sp., *Lichas* sp., *Sphaerocoryphe* sp., and *Acidaspis* aff. *bispinosus* are now considered too poor and unsatisfactory even for generic determination, so they do not here receive any further notice. The specimen identified as *Agnostus agnostiformis* is missing. The free cheek of a trilobite from the Shangort beds of Tourmakeady (loc. 322), which was described and figured as *Apatocephalus* ? sp. (1909, p. 148, pl. vi, fig. 9), must still remain as of doubtful generic reference. The Tramore Limestones in the south-east of Ireland which were previously mentioned (1909, p. 142) as having a comparable fauna are now considered to represent a higher Ordovician horizon.

Ectenonotus connemaricus (Reed)

In a recent paper on some Ordovician trilobites from Nevada Holliday (1942, pp. 471–8, pl. 73, figs. 1, 2 ; pl. 74, figs. 8–10) records the occurrence there of the Irish species *Ectenonotus connemaricus* (Reed) (1909, p. 146, pl. vi, figs. 6, 7). This was founded on pygidia (A 10382a, b) from the Shangort beds (loc. 212) of the Lower Ordovician of the Tourmakeady district, Co. Mayo, and was originally referred to the genus *Cybele*,

but undoubtedly belongs to the same genus as "*Encrinurus*" *octocostatus* Reed which Raymond transferred to his genus *Ectenonotus* (1920, p. 279; 1925, p. 137), a change which has been accepted by the present author (1928, p. 68). The genotype is *Amphion westoni* Billings (1865, p. 321, figs. 307a, b). Holliday figures not only pygidia of *E. connemaricus* but also one glabella (1942, p. 476, pl. 73, figs. 1) from Nevada. The specimen [A 10405] from loc. 322 in the Shangort beds recorded in the list of fossils (1909, p. 125) as *Encrinurus* aff. *multisegmentatus* is apparently an imperfect example of a pygidium of *E. connemaricus*. A large pygidium in the condition of an external impression [A 10427] which was referred to *Phacops* (*Chasmops*) sp. from the Shangort beds of Tourmakeady (loc. 212) belongs also to this species. The pygidia from the tuff of Glensaul (loc. 62) named *Phacops* (*Chasmops*) aff. *odini* (1910, p. 277) cannot be identified in the collection, but should probably have been referred to the genus *Ectenonotus*.

Ectenonotus octocostatus (Reed)

This species was first recorded and described as *Encrinurus* sp. (1909, p. 147) from the Shangort beds of Tourmakeady; later it was figured and redescribed as *octocostatus* from a better specimen of a pygidium (A 10416) in the same beds in the Glensaul area (1910, p. 177, pl. xxii, figs. 4a, b), and this specimen must be regarded as the type. Raymond (1920, p. 295; 1925, p. 138) transferred the species to his genus *Ectenonotus*. The fewer pleurae in the pygidium and the termination in the case of the last three or four pleurae before reaching the margin of the pygidum are distinctive features separating it from *E. connemaricus*; the axis is also more elongated and tapers more slowly. But the species are apparently closely allied, and one pygidium figured by Holliday from Nevada (1942, pl. 74, fig. 10) as *E. connemaricus* seems to be more like *E. octocostatus*. The nearest allied if not identical species is the genotype of *Ectenonotus*, *Amphion westoni* Billings (1865, p. 321, fig. 307b), the pygidium of which seems almost indistinguishable, while the glabella of that species (fig. 307a) resembles the head-shield (A 10419) from the Shangort beds of Glensaul which the author described and figured (1910, p. 276, pl. xxii, fig. 5) as *Pliomera pseudoarticulata* (Portlock), but which Raymond (1925, p. 295) with much probability associated with the pygidium of *E. octocostatus*. It also resembles the species from Nevada named *E. marginatus* by Holliday (1942, p. 476, pl. 74, fig. 2), and at any rate it cannot certainly be regarded as identical with Portlock's species owing to the shape of the glabella and position of the lateral furrows.

Pliomerops shangortensis sp.nov.

The pygidium (A 10391) from the Shangort beds of Tourmakeady which was figured (1909, p. 145, pl. vi, fig. 5) as *Pliomera* aff. *barrandei* (Billings) was regarded as an unnamed species of *Pliomerops* by Raymond (1925, p. 155). Holliday (1942, p. 474) considers that it has affinities with the genera *Pilekia* and *Parapilekia*, and is not identical with *Pseudomera barrandei* (Billings), the first figure of which given by Billings was a glabella (1865, p. 288, fig. 277a) which certainly has the characters of Holliday's genus *Pseudomera* (1942, p. 473, pl. 73, figs. 5, 6), though Raymond

(1925, p. 153) put Billings's species in *Pliomerops*. Holliday's figures of the pygidium from Nevada which he ascribes to *Pseudomera barrandei* (1942, pl. 73, figs. 7, 9) are not like Billings's figure 277b (*op. cit.*) of that member, the latter being more transverse with more horizontally extended pleurae which also have longer spinose free ends, so that in these respects it resembles our Tourmakeady specimen much more than Holliday's example from Nevada. We can therefore hardly consider the specimens from these widely separated localities to be identical or even perhaps referable to the same genus. We may rather compare *Pliomera dactylifera* Poulsen (1927, p. 307, pl. xx, figs. 36, 37) from the Upper Canadian of Greenland, which as he remarks has a pygidium strikingly similar to that of *Pliomera barrandei* (Billings). *P. actinura* (Dalman) as figured and described by Wiman (1907, p. 87, pl. vii, figs. 9–12) from the Orthoceras Limestone of the Baltic may also be allied ; but neither of these have such long free pointed and curved spinose ends to the pleurae as our Tourmakeady specimen. Apart from the short conical axis these characters resemble *Parapilekia* Kobayashi (1934, p. 570), but on the whole it seems safest to refer it to the genus *Pliomerops*.

Pliomerops (*Protopliomerops*) cf. *primigenus* (Angelin)

The imperfect pygidium (A 10380) from the Shangort beds (loc. 212) of Tourmakeady showing only the impression of the free spinose ends of the pleurae which was figured and referred with a query to the genus *Acidaspis* (1909, p. 148, pl. vi, fig. 8) should be placed in the genus *Pliomerops* as Raymond (1925, p. 155) suggested. It appears to be closely comparable with *Pliomerops primigenus* (Angelin), a species which was put by its founder (1854, p. 90, t. xli, fig. 15) in the genus *Pliomera*. Brögger (1882, p. 134) transferred it to *Amphion*, and Moberg and Segerberg (1906, p. 101, t. vii, figs. 12–14) to *Cyrtometopus*, where it was also placed by Schmidt (1907, p. 99, t. 1, fig. 3, text-fig. 10) and Barton (1916). Raymond (1924, p. 458) referred it to the genus *Pilekia* Barton (1916, p. 113), and recently Kobayashi (1934, p. 570) and Harrington (1937, p. 120, t. v, figs. 2, 3 ; 1938, p. 183, t. vi, figs. 9, 12, 14, 15, 20) have put it in the genus *Protopliomerops* (Kobayashi, 1934, p. 568, genotype *Pl. seisonensis* Kob.). This seems to be only a subgenus of *Pliomerops*. *Protopliomerops punctulifera* Kobayashi (1937, p. 472, pl. vi, figs. 4, 5) from the Cambro-Ordovician beds of Bolivia seems to possess somewhat similar pygidial characters. The pygidium of our specimen may also be compared with that of *Amphion escoti* Bergeron (1895, p. 472, pl. iv, figs. 6–8) from Languedoc, which Harrington considers may be identical with *Pliomerops primigenus*.

Pliomerops (*Protopliomerops*) cf. *insolitus* (Poulsen)

The small head-shield (A 10420) from the Shangort beds of Glensaul (1910, pl. xxii, fig. 6) which was figured as probably a young individual of *Pliomerops pseudo-articulata* may belong to *P. primigenus*, but it more resembles *Pliomera insolita* Poulsen (1927, p. 307, pl. xx, fig. 32) from the Canadian of Greenland, a species which Öpik (1937, p. 116, footnote) thinks probably belongs to *Protopliomerops*. *P. punctulifera* Kobayashi (1937, p. 472, pl. vi, figs. 4, 5) appears to have somewhat similar cranidial

characters. The head-shield of the Lower Ordovician trilobite *Strototropis laeviuscula* Raymond (1937, p. 1126, pl. 3, fig. 24) from the Highgate Formation of Vermont seems also to bear a considerable resemblance.

Kawina divergens sp. nov.

The imperfect pygidium (A 10396) from the "Calcareous Series" of Tourmakeady (loc. 45) described and figured as *Pliomera* aff. *fischeri* (Eichw.) (1909, p. 144, pl. vi, fig. 4) does not seem to have lost any of its anterior segments as was suspected, but to have possessed originally only three pleural segments, all of which are preserved. The pygidium ascribed by Billings (1865, p. 284, fig. 271c) to *Cheirurus vulcanus* from the Chazy Limestone and subsequently put by Raymond (1925, p. 143) in the genus *Kawina* Barton (1916, p. 117, fig. 9) has likewise only three pleural segments and they are blunt and unfurrowed, but are tuberculated and in contact; the axis, however, is similarly conical, short, and broad. *Pliomera fischeri* (Eichw.) as figured and described by Schmidt (1881, p. 191, t. xiii, figs. 1–8) has a pygidium completely different from our Tourmakeady specimen and cannot be regarded as even allied to it. Raymond (1925, p. 144) considered this Tourmakeady pygidium to belong to a species closely related to *K. vulcanus*, but he gave it no specific name. The Scandinavian species "*Cyrtometopus*" *scrobiculatus* Ang. (1854, p. 35, pl. xxii, fig. 3) appears to have a pygidium much like our Irish specimen, having three bluntly rounded slightly divergent pleurae, but no specimen of it has been available for comparison. Apart from the median row of punctae on the first two pleurae we may also draw attention to the Bohemian species *Cheirurus* (*Eccoptocheile*) *claviger* Beyrich, as figured and described by Barrande (1852, p. 772, pl. 40, fig. 6), for it has three similarly shaped and divergent pleurae and an axis of the same character as the Irish specimen. *Cheirurus sedgwicki* McCoy (Salter, 1866, p. 73, pl. v, fig. 17) from the Llandeilo of Wales apparently belongs to the same group as *C. claviger* Beyr. (Reed, 1896, p. 120), though it agrees less closely with our present specimen. But as the author has remarked (1896, pp. 207, 208) the pygidium in the Cheiruridae when taken alone is a treacherous guide, and in many cases appears to have followed a line of development independent of the head-shield. Thus *Sphaerexochus parvus* Billings has, according to Raymond (1925, p. 149, pl. 10, fig. 5), a pygidium with three pairs of flattened blunt pleurae, which apart from the fact that they are in contact for their whole length, bears a great resemblance to that of *Kawina divergens*.

Kawina cf. *vulcanus* (Billings)

An imperfect small pygidium (A 10421) from the gritty Shangort beds of Glensaul was labelled *Pliomera pseudoarticulata* Portl. with a query, but was not described. It is, however, of sufficient interest to merit a description, for it most nearly approaches that of *Cheirurus vulcanus* Billings (1865, p. 284, fig. 271c) which Raymond (1905, p. 367, pl. 14, fig. 16) following Clarke (1897, p. 738), at first put in the genus *Pseudosphaerexochus*. This species, as above mentioned, was referred by Barton (1916, p. 117, fig. 9) to his genus *Kawina*, with which view Raymond subsequently (1925, p. 143) agreed.

Our specimen shows three pairs of flattened subequal parallel-sided broad contiguous pleurae; the last pair being straight, parallel and in contact, but separated at their origin by the very small short triangular apical segment of the axis which is wedged in between them; the rest of the axis is hidden in the matrix and needs developing with a needle. All three pairs of pleurae are in contact for their entire length and their ends seem to be blunt and not to project much beyond the margin. The surface of the pleurae is covered with rather close low small tubercles, as in *K. vulcanus*.

From this species our specimen seems only to differ by the pygidium being rather narrower and the pleurae relatively rather longer, while from *K. divergens* it differs by the pleurae being in contact for their whole length, and not divergent at their ends, and also by being longer and tuberculated instead of smooth.

Cybelopsis ? sp.

Pygidium small, subquadrate, as wide as long, with straight truncated posterior edge. Axis short, broadly conical, convex, about one-third the length of the pygidium, composed of five complete rings, followed by long, much narrower, non-annulated convex median post-axial piece very slightly tapering to posterior edge of pygidium. Lateral lobes composed of five pairs of simple rounded coarsely granulated pleurae in contact for their whole length, curving out strongly at first, then bending gently inwards to run back parallel to blunt tips.

Remarks.—There is only one small pygidium (A 10431) measuring about 5 mm. in length and breadth, from the Shangort beds (loc. 5) of Tourmakeady. It has one side and the centre of the pygidium perfect and the other side nearly so.

Apart from the shorter axis and narrower post-axial border it bears a considerable resemblance to *Cybelopsis speciosa* Poulsen (1927, p. 305, pl. xx, figs. 9, 38–43, text-fig. 6) from the Ordovician of Greenland. But we may also note that Poulsen remarks on the similarity of the genus in many respects to *Pliomera*, and but for the median post-axial portion it recalls *Pliomerops canadensis* (Billings) as figured and described by Raymond (1910, p. 238, pl. xxxvi, fig. 12; 1925, p. 152) from the Chazy Limestone of Vermont. The Burmese trilobite *Pliomera* (*Encrinurella*) *insangensis* Reed (1915, p. 50, pl. viii, figs. 15–21) resembles both this and the Canadian species (Reed, 1928, p. 69) in certain respects.

Bathyurellus glensaulensis Reed

This species (1910, p. 274, pl. xxi, figs. 1–3*b*) from the tuff (loc. 62) of the Glensaul area, of which two imperfect head-shields (A 10410, 10411) and a free cheek (A 10412) were described and figured, was previously compared with *B. formosus* Billings (1865, p. 266, fig. 240), *B. expansus* Billings (1865, p. 318, fig. 306), and *B. brevispinus* Raymond (1905, p. 337, pl. 10, figs. 13–15). It is also allied to *B. teicherti* Poulsen (1937, p. 53, pl. 7, figs. 2–5) from the Lower Ordovician of East Greenland and to *B. nitidus* Billings (1865, p. 265, fig. 249). Raymond (1925, p. 76) has remarked on its resemblance to *B. brevispinus* (1905, p. 337, pl. 10, figs. 13–18) from the Chazy Limestone of the Champlain valley, but *B. expansus* seems to be much closer, if not identical.

Bathyurellus ornatus sp. nov.

The cast and impression of the exterior of the imperfect pygidium showing part of the doublure as well as most of the axis and the greater portion of one pleural lobe [A 10418a, b] from the limestone of Glensaul (loc. 155) was recorded and figured as *Niobe* sp. (1910, pl. xxii, figs. 3a, b), but it cannot now be considered to belong to that genus, and it also merits a fuller description than was then given, for it can be regarded as a distinct species of *Bathyurellus*.

Pygidium semi-circular or semi-oval, very gently convex. Axis rather less than one-third the width of the pygidium, and about three-fourths its length, tapering slowly to a blunt point, the tip slightly invading the border, composed of five rings in the anterior portion (the posterior half is not clearly preserved). Pleural lobes very gently convex, nearly horizontally extended, composed of four pleurae, each slightly elevated, unfurrowed, and having a broad flat or slightly concave top and bevelled edges, separated by deep narrow subangular furrows, both pleurae and furrows dying out laterally on reaching the broad gently concave border. Doublure about one-fourth the width of the pygidium laterally, increasing to about one-third its length posteriorly, covered with numerous thin concentric nearly regular lamellae. Surface of pygidium ornamented with weak, closely set terrace-lines crossing the pleurae obliquely, but bending forwards in a median angulation on the axis.

Dimensions.—Length of pygidium, 23 mm.; width of pygidium, *c.* 30 mm.; width of axis (front end), *c.* 9 mm.

Remarks.—This pygidium must be referred, as stated above, to the genus *Bathyurellus* and not to *Niobe*, and its ornamentation seems to resemble that of *B. tenuis* Poulsen (1927, p. 303, pl. xx, fig. 30) from the Upper Canadian of Greenland, but its ornamentation is unusual and recalls species of *Ptychopyge* and *Scutellum*. The general characters of the pygidium of our specimen, particularly the few pleurae dying out before reaching its edge and the broad margin, are found in *Bathyurus amplimarginatus* Billings (1865, p. 353, fig. 341a), figured by Twenhofel (1938, p. 71, pl. 10, fig. 13), from the Mingan Islands, and to this species it is certainly allied. We may suspect that *Asaphus* ? *asiaticus* Endo (1932, p. 112, figs. 11–17) from the Ordovician of Shensi should be placed in the same genus and considered related to this Glensaul species, for Endo was very doubtful as to its true generic reference. We may see, however, a greater resemblance to the pygidium which Whitfield (1891, p. 38, pl. ii, fig. 12; Raymond, 1913, p. 54) associated with the head-shield of *Bathyurus* (*Bathyurellus*) *glandicephalus* from the Fort Cassin beds of Vermont, which are of Canadian (Beekmantown) age; its pygidium has the same outline, an axis of the same shape and the same number of pleurae, while the whole surface is stated to be covered with fine wavy lines as is the case in our Glensaul specimen.

Bathyurus ? *reynoldsi* sp. nov.

The slightly distorted pygidium (A 10414) from the tuff of the Glensaul area (loc. 62) which was described and figured (1910, p. 275, pl. xxi, fig. 5) as *Bathyurus* cf. *timon* Billings (1865, p. 261, fig. 244) of the Quebec group of Newfoundland, was incorrectly drawn and gave a somewhat

incorrect impression of its characters which were also not fully described. The generic reference of the Newfoundland species was doubted by Bassler (1915, p. 107), and Raymond (1913) did not mention it in his revision of the genus *Bathyurus*, though later (1925, p. 154) he put it in his genus *Petigurus*. The detailed description of this Glensaul specimen is as follows :—

Pygidium semicircular, moderately convex. Axis stout, semi-cylindrical, tapering slightly to a blunt extremity, prominent, convex, composed of four complete rounded rings and of a non-annulated posterior portion less than one-third its length, ending at the inner edge of a narrow border ; lateral lobes arched, composed of three pairs of thick convex, broad, unfurrowed pleurae and of narrow half-pleurae on the front edge, the last pair very short and subtriangular ; all the pleurae are separated by deep narrow furrows and end abruptly at the border. Surface of axis and pleurae coarsely tuberculated. Border narrow ?, depressed, smooth. Doublure moderately convex, concentrically striated, rather wider than the border.

Dimensions.—Length, 19 mm. ; width, 27 mm.

Remarks.—In addition to the close resemblance of this pygidium to that of *B. timon* Billings from which it differs chiefly by its more semicircular shape, we may mention the species from the Pogonip formation of Nevada named *Bathyurus pogonipensis* by Hall and Whitfield (1877, p. 243, pl. i, figs. 33, 34) ; the latter species has four pleurae on the lateral lobes. *Elvinia roemeri* (Shumard) as redefined by Bridge and Girty from the Upper Cambrian of Texas (1937, pp. 251–5, pl. 67, figs. 3a, b, pl. 69, figs. 6, 7, 8, 10, 20, 21) has a pygidium of apparently the same general construction and shape as the Glensaul specimen, but is without tuberculation. We hestitate to remove it to that Cambrian genus which was established by Walcott. Our specimen differs from typical members of the genus *Petigurus* by the pygidial pleurae not being strongly cleft at their extremities or deeply furrowed and broken up, although there is a noticeable similarity in the figure of an imperfect pygidium named by Poulsen (1937, p. 56, pl. 7, fig. 11) *Niobe groenlandica*, particularly in the costation, but not in the ornamentation. We can hardly regard our specimen or Poulsen's as belonging to that genus in its strict sense, and we may rather place it with a query in *Bathyurus*.

Petigurus ? cf. *crassicornis* Poulsen

Poulsen (1937, p. 49, pl. 6, figs. 1–13) described and named *Petigurus groenlandicus* from the Lower Ordovician of Cape Weber, East Greenland, observing its close resemblance to *Bathyurus nero* Billings (which Raymond put as the type of his genus *Petigurus*). An imperfect glabella (A 10413) from the gritty tuff of Glensaul (loc. 62) was previously figured by the author (1910, p. 275, pl. xxi, figs. 4a, 4b) as *Bathyurus* cf. *nero* Billings.

But this figure incorrectly depicted a broad fixed cheek behind the eye which misled Raymond (1913, p. 59) ; the eye also was placed too far forward in the drawing, and the posterior wing of the fixed cheek was not drawn small and short. We may better compare the Glensaul specimen with *Goniurus crassicornis* Poulsen (1927, p. 302, pl. xx, fig. 22) from the Upper Canadian of North-West Greenland, and with *Bathyurus strenuus*

Billings (1865, p. 188, fig. 204) from the Canadian of Quebec which Raymond (1913, p. 68) put doubtfully in his genus *Lloydia*, a reference queried by Bassler (1915, p. 753). The generic definition of *Goniurus* given by Raymond (1913, p. 65) does not, however, fit the glabella of our specimen or of Poulsen's species which more resembles that of *Petigurus*.

Hystricurus cf. *tuberculatus* (Walcott)

There is the greater part of a small head-shield (A 10430) from the Shangort beds (loc. 293) of Tourmakeady which was recorded in the list of species as *Cyphaspis* ? sp. (1909, p. 125), but was not figured or described. It is comparable to *Bathyurus tuberculatus* Walcott (1884, p. 91, pl. xii, fig. 9) which Poulsen (1937, p. 34) put in the genus *Hystricurus* to which Bassler (1915, p. 657) had previously referred it with a query. A similar species from the Upper Pogonip of Nevada was put by Walcott in the genus *Cyphaspis* with a query (1884, p. 93, pl. 12, fig. 10), but Raymond, (1913, p. 61) referred it to *Haploconus*.

The Shangort specimen has a much swollen ovoid glabella coarsely tuberculated without any trace of lateral lobes or furrows. The free cheeks are imperfect, but meet in front of the glabella forming a lower narrower swollen tuberculated band separated from it by a deep continuous furrow. The species *Hystricurus ravni* Poulsen (1927, p. 283, pl. xviii, figs. 5–10) from the Upper Ozarkian of North-West Greenland, and the Manchurian species *H. convexus* Endo (1935, p. 217, pl. xv, figs. 6–8) from the Lower Ordovician of Liaotung appear to bear a considerable resemblance to it.

Illaenus weaveri Reed

Raymond considered (1925, pp. 110, 167) this species as allied to *Illaenus alveatus* Raymond (1925, p. 109, pl. 7, fig. 5) from Newfoundland, while the present author in his original description of *I. weaveri* (1909, p. 142, pl. vi, figs. 1–3) from the limestone of Tourmakeady (loc. 58) regarded it as comparable with *I. dalmani* Volborth and *I. esmarcki* Schloth. (Reed, 1910, p. 272). The free cheek (A 10489) ascribed to it (*op. cit.*, pl. vi, fig. 3) was badly drawn, the eye being made much too large in proportion to the size of the cheek.

The species *I. hinomotoensis* Kobayashi (1934, p. 560, pl. iii, figs. 22–9) from the Lower Ordovician of South Chosen has a pygidium closely resembling that of *I. weaveri*, but the head-shield is quite different. We may note that Walcott and Resser (1924, p. 5, pl. i, figs. 4–14) establish a new genus *Koldinia* for a form *K. typa* which they state is much like *Illaenus*, from the Ozarkian of Nova Zembla. But while the head-shield of that trilobite much resembles that of this Tourmakeady species, the peculiar narrow rim in front is not visible in any of our specimens.

Illaenus cf. *consimilis* Billings

The specimens from the limestone of Tourmakeady which were mentioned (1909, p. 144) as allied to *Illaenus chudleighensis* Holm, may be better compared with *I. consimilis* Billings (1865, p. 277, fig. 263a, b, c). There is one imperfect head-shield (A 10456) from loc. 45 measuring about 14 mm. in width between the eyes and apparently only 7 mm. in

length, with a short broad parallel-sided glabella, also 7 mm. in width, which agrees well with Billings's figure ; and there is another specimen (A 10421) from the Shangort beds of Glensaul. The small detached free cheek (A 10385) which was described (but not figured) as *I.* cf. *chudleighensis* from loc. 45 may probably also be referred to it. A small transverse and short pygidium (A 10457) from loc. 44 with a slightly sunken short convex indistinctly defined triangular axis measures 9 mm. in width and a little over 4 mm. in length, and shows a broad concentrically striated doublure of uniform width, about two-fifths the length of the pygidium. The lateral angles are truncated at about 110°–120° to the anterior margin which seems to be straight, except for the projection of the axis, so that in its proportions, transverse extension, axis, and general characters this pygidium much resembles *I. consimilis*, the type of which comes from stages in Newfoundland which contain a Chazyan fauna (Raymond, 1925, p. 164).

Nileus armadillo Dalman

The pygidium (A 10417a, b) from the " Calcareous series " of Glensaul (loc. 361) was correctly referred by the author (1910, p. 273, pl. xxii, figs. 2a, 2b) to this species which Moberg and Segerberg (1906, p. 93, t. vi, figs. 1–5) figure from the Ceratopyge Limestone of Scandinavia. The glabella (A 10416) from the gritty tuff (Shangort beds) of Glensaul (1910, p. 273, pl. xxii, fig. 1), similarly identified, appears to possess the typical characters of the species as figured by Schmidt (1904, p. 64, t. viii, figs. 12–18). Raymond (1925, p. 167) compares the Glensaul form with *Nileus scrutator* Billings (1865, p. 274, fig. 260 ; Raymond, 1925, p. 84, pl. iii, fig. 17).

It may be remarked that Gortani (1934, p. 73, t. xvii, figs. 2–4) has described and figured *N. armadillo* from the Karakorum, and the present author has likewise described it from Yunnan (1917, p. 19, pl. viii, fig. 5).

Symphysurina cf. *elegans* Poulsen

The imperfect impression of a glabella (A 10397) from the Shangort beds (loc. 322) of Tourmakeady, was figured as *Symphysurus* ? sp. (1909, p. 150, pl. vi, fig. 12), but later (1910, p. 273) was erroneously believed to belong to *Nileus armadillo* Dalman. This may now be referred to the genus *Symphysurina* on account of its resemblance to *S. elegans* Poulsen (1937, p. 37, pl. 2, figs. 11–18), though the eye-lobes seem to be rather larger. *S. eurekensis* (Walcott) (1884, p. 97, pl. vii, fig. 4) from the Upper Pogonip of Nevada may also be compared, and *S. incipiens* (Brögger) (1882, p. 58, t. 1, figs. 1, 2) from stage 3aα in the Oslo area may be allied. The distinction between the genera *Symphysurus* Goldfuss and *Symphysurina* Ulrich lies only in the character of the cephalic doublure which is not preserved in our specimen.

There is an imperfect free cheek (A 10440) from the Shangort beds (loc. 212) of Tourmakeady, with the genal angle broken which especially resembles some species of *Symphysurina* such as *S. woosteri* Ulrich (Walcott, 1925, p. 115, pl. 21, figs. 1–11) which has a glabella and eye lobes much like our specimen and occurs in the Upper Ozarkian of

Wisconsin. The species *S. porifera* Poulsen (1927, p. 286, pl. xviii, figs. 20–4) occurring in the Upper Ozarkian of Greenland may also be compared.

Telephus hibernicus Reed

Ulrich (1930, p. 17, pl. 2, figs. 18, 19) refigures this species (1909, p. 149, pl. vi, figs. 10, 11) which was named by the author from several small somewhat imperfect specimens (A 10398–9) from the limestone (loc. 58) of Tourmakeady. He considers its relationship with *T. bicuspis* Angelin from Norway probable, as was mentioned in the original description. No further specimens have been found.

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The Origin of the West Cumbrian Haematites [1]

By F. M. Trotter

HAEMATITES of great commercial importance occur in West Cumberland, chiefly in the Carboniferous Limestone. Worked as early as the twelfth century the annual output reached half a million tons by 1861, since when the output has varied between that figure and one million tons. During these years of active exploitation many ore-bodies in the exposed ore field were worked out and active exploration is now concentrated around and to the south of Egremont, where the Carboniferous Limestone plunges beneath the New Red rocks. Among the problems confronting the searchers for new ore-bodies in this concealed ore field there is one of long standing, upon which unanimity has not been reached, namely the origin of the haematites. The question of origin is not one of mere academic interest. Its solution affords an important clue in the search for new ore-bodies. Two theories—magmatic origin and deposition from meteoric waters—are and have been propounded by rival advocates during the last fifty years. J. D. Kendall (1893) attributed the origin of the ores to ascent of magmatic solutions in pre-Permian times. To him we owe the theory of metasomatic replacement of the limestone by haematite, now generally accepted.

Goodchild (1889–1890) considered that the New Red rocks were the original source of the iron ; from these rocks the mineral was carried in solution by downward percolation of meteoric waters. Of recent writers Smith (1924) is in agreement with Goodchild. MacDonald (1925) and Dixon (1928) support Kendall in considering that the ores are of magmatic origin, but on the question of the age of the deposits they agree with Goodchild. Kendall (1920) links the haematite deposits with the lead-copper veins of the Lake District as products of one magmatic mineralization. On this point also Kendall is supported by Dixon, who, however, is impressed by the evidence for descending iron-bearing solutions in a limited area near Egremont, where he considers that descending meteoric water met ascending magmatic solutions and carried them down to the basal limestones.

As emphasized by Goodchild the theory of downward percolation of meteoric waters from the New Red Sandstone Series has the merit of explaining not only the haematite deposits of West Cumberland but also the reddening of the Carboniferous strata, frequently found in north-western England beneath the base of the New Red rocks. To assess the validity of this theory beyond the limits of the ore field the writer examined the reddened and sporadically haematitized Carboniferous strata that fringe the base of the New Red Sandstone Series in Edenside and around the margins of the Carlisle Basin, and it was concluded that the reddening of the Carboniferous strata has resulted from the weathering under desert conditions of the pre-New Red land surface and the consequent oxidation of the ferrous iron contained in the Carboniferous rocks. " The theory of origin of the West Cumbrian haematites by meteoric waters descending

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from the New Red Sandstone finds no support in the reddened Carboniferous strata that fringe the New Red Sandstone in Edenside and the Carlisle Plain. This theory must stand or fall on the ore field evidence alone" (Trotter, 1939).

In the present paper the evidence bearing on the origin of the West Cumbrian haematites is outlined, and it is concluded that the haematite mineralization is magmatic in origin and took place under thick cover, which probably included Keuper Marls and Liassic shales, below the level of the local ground waters. The mineralizing solutions ascended in the older Palaeozoic rocks where these directly underlay the New Red Sandstone Series to the east of the present ore field. On entering the basal members of the Series the solutions migrated laterally, down dip, in a westerly direction, into areas underlain by Carboniferous rocks, where they descended principally along lines of fracture. The migration of the solutions is limited in a westerly direction by the lateral changes from conglomerate into shales that take place in the basal members of the New Red Series.

Age of the Mineralization

Recent observers, with the exception of Kendall, agree in regarding the mineralization as of post-Triassic age. Nevertheless the occasional presence of undoubted pebbles of haematite in the New Red Brockram, as for example at Humphrey Head, has puzzled many observers. The evidence for the pre-Permian age of the reddening and associated sporadic haematitization of Carboniferous rocks in the Carlisle and Edenside areas, appears at first sight to support Kendall's contention. In fact these pebbles must have been derived from this pre-Permian haematite concentration. The evidence, however, for a post-New Red Sandstone mineralization is overwhelming. In recent borings for iron-ore, cores have shown the New Red Brockram—pebbles and matrix alike—converted into haematite. Other specimens show a concentric development of kidney-ore between and around pebbles of the Brockram. In many bores the lower part of the New Red Sandstone (St. Bees Sandstone) is heavily impregnated with haematite. Furthermore, as first pointed out by Smith (1924, pp. 40–1), the ore-bodies lie along and are associated with faults, which shift the Trias. Kendall explained this by postulating two movements along such faults, the first of pre-Permian age, which was followed by the mineralization, and the second of post-Triassic age which shifted the ore-bodies. But examination of the ore-bodies does not support this view. They are not brecciated against the faults and not infrequently the ore-bodies cross post-Triassic faults (as for example in Beckermet Mine) without visible displacement. No case is known in which an ore-body has been appreciably dislocated. Slickensided surfaces have been reported from the ore-bodies, and some of these may indicate slight minor adjustment since ore deposition. But even this evidence cannot be accepted at its face value. For example, a slickensided surface was seen in what appeared to be ore on the downcast side of a fault in Crowgarth Mine, Cleator Moor. Closer examination, however, indicated that a thin film of haematite coated a slickenside surface of limestone.

On the upcast side of the fault and immediately adjacent to the slickensided surface a mass of pencil ore, displaying numerous examples of intergrowing kidneys, showed no sign of fracture or of movement.

There is no evidence of appreciable movement subsequent to the haematite mineralization. The post-Triassic rocks had received their present westerly tilt and they had been dislocated by a system of tension faults prior to the mineralization.

Critical Examination of the Theory of Ore Formation by Downward Percolating Meteoric Waters

It has been shown (Trotter, 1939) that there is no downward movement of ferric oxide from the New Red Sandstone to the Carboniferous rocks in adjoining areas outside the limit of the ore field. This is in full accord with the chemical character of ferric oxide which is practically insoluble in normal meteoric waters as the following analyses of water from the New Red Sandstone testify :—

Name of Well.	*Water Bearing Horizon.*	*Amount of $Fe_2O_3 + Al_2O_3$ per 1,000,000.*
Bewdley Town Supply	Lower Mottled Sandstone.	Trace.
Malvern Urban District Supply.	Upper Mottled Sandstone.	1·6 and 1·2.
Upton on Severn, Red Hill bore.	Keuper Marl and Lower Keuper Sandstone.	2·5 at overflow, 4·2 at depth of 1,700 feet, and temperature of 66° F.

Clearly this insignificant order of solvent action is wholly incapable of dissolving and redepositing the large amounts of haematite required to form the ore-bodies of West Cumberland. To take one example: the amount of ore, extracted or proved, in the Florence-Winscales ore-body amounts to 25,000,000 tons. This ore-body underlies the New Red Sandstone Series which has been examined in scores of near-by borings. Apart from the lower layers the full sequence of the St. Bees Sandstone is normal in character and colour, shows no signs of leaching, and is indistinguishable from the same rock in areas outside the limits of the ore field. The lower layers are frequently impregnated with haematite (see Table on p. 77).

Positive evidence against the theory is also available. The ore-body at Winscales Mine lies beneath thick New Red cover, and Mr. Sherwen informs me that in the sinking of No. 1 Shaft the ore deposit lay beneath the local water table, held up by shales in and near to the base of the St. Bees Sandstone. The ore-body struck in the No. 1 Shaft was dry, and a heading was driven northwards in dry ore for some 350 yards. Other headings in the mine, driven in ore or in limestone, make no water except in areas where borings have penetrated through St. Bees Sandstone and Brockram into the Carboniferous Limestone. To guard against influx of water recent boreholes are plugged with concrete after completion. In places the extraction of ore, up to 80 feet thick, has caused a collapse of strata that has also let in the water from the overlying sandstones.

If, in the deep Winscales Mine under thick New Red cover, the ground waters of to-day lie above the ore in the Carboniferous Limestone, it is

reasonable to suppose that similar conditions obtained during the period of ore deposition when the cover was considered to be so thick as to include Keuper Marls and Liassic shales. Nevertheless there is abundant evidence that ore-bearing solutions reached the Carboniferous Limestone from the overlying *Brockram* (see later).

THE MINERAL ASSEMBLAGE

Dixon (1928) has pointed out that the mineral assemblage associated with the West Cumbrian haematite affords evidence of the magmatic origin of those deposits. With this I agree, and such additional information as has been acquired supplements his evidence on this point.

Several varieties of haematite occur, and brief notes are given only on those varieties that have some bearing on the suggested magmatic origin of the deposits.

Kidney or Pencil Ore.—A botryoidal form of crystalline haematite prevalent throughout the ore field, this mineral is an important constituent of many of the iron ore veins found in the Lower Palaeozoic rocks. It is pure haematite, free from combined water. It appears to be absent from the non-magmatic limonites that are of world-wide distribution, but it is impossible to confirm this with certainty.

Specular Iron-Ore or Specularite.—This is another form of crystalline haematite which, although not so abundant as kidney ore, also appears throughout the ore field, usually in cavities within ore-bodies, but also in veins up to 2 feet wide. It may be produced artificially, only at a temperature of 300° C. It is a characteristic mineral of magmatic haematites.

Sosman and Hostetter (1917) examined a number of specimens of specularite, including one from Cumberland, and found they were magnetic, indicating that the ore carries magnetite in solid solution. I have tested several specimens of specularite from West Cumberland and found that when the mineral is ground to powder it may be picked up with a hand magnet. Primary magnetite is of magmatic origin.

Metalliferous minerals associated with the Cumbrian iron ores are: manganite, chalcopyrite, pyrite, siderite, and galena. Gangue minerals are: barytes, fluorite, quartz, dolomite, and calcite.

Manganite.—This mineral is, or has been, worked in commercial quantities in the iron ore mines around Bigrigg. I have examined its mode of occurrence in the Wyndham Mines. Here it occurs within and on the fringe of a haematite ore-body in the 4th Limestone. Lenses seen in cross-section measure 6 feet in length and 2 to 4 feet in depth. Strings of manganite from the lenses vein the enclosing haematite, but no haematite occurs within the manganite lenses. Occasionally lenses of manganite are found adjacent to lenses of white barytes of similar size and lenses of the latter mineral also occur within the haematite ore-body.

Chalcopyrite and Pyrite.—Copper ore occurs in several iron ore mines, including Crowgarth Mine, Cleator Moor. Smith (1931, p. 270) states that the copper ore and associated pyrite were not in contact with the haematite, and he concluded that copper minerals were deposited before later mineralizing solutions converted the limestone into haematite. I cannot accept this conclusion. On a visit to this mine in 1939 I was

kindly shown several occurrences of copper ore, and although on one level haematite does not occur in association with the copper ore as mentioned by Smith, occurrences were seen within the haematite deposit at another level which recalled similar occurrences of barytes and manganite in other haematite bodies. Lenses of sulphide minerals up to 5 feet in length and 4 feet in depth were enclosed in the haematite ore-body which hereabouts contained much kidney ore.[1] Much of the copper was oxidized to malachite. No haematite occurred in the lenses of the metallic sulphides. These occurrences strongly suggest that the sulphides were deposited somewhat later than the haematite. On the other hand Dixon (1931) describes hand specimens from the tip of the neighbouring Eskett Mine in which the copper ore is veined by haematite and is moulded on pink barytes. Probably there was an early and late phase of haematite deposition (see, for example, barytes and fluorite). Be that as it may it is beyond question that the iron-copper minerals are the product of one mineralization.

Galena.—This mineral has been found in strings in the old Crossgill Haematite Mine (Dixon, 1931).

Barytes.—This mineral is associated with the West Cumbrian Haematites throughout the ore field. The extent of the association may be appreciated by a perusal of the table on p. 77, wherein is listed the occurrences of the two minerals in recent borings. It occurs as lenses within the ore-bodies (as, for example, occurrences in Wyndham Mine). Also it is found separately in the limestone. The thickest vein known to me to occur in this manner was proved in Winscales Mine, where a vein 3 feet wide was struck. Although undoubtedly deposited after the main mass of haematite this latter mineral in the form of specularite is found not infrequently coating barytes crystals. According to Rudler (1897, p. 147) barytes is pseudomorphed by haematite.

Barytes is found characteristically as a gangue mineral of magmatic ores, but it is known to migrate, there being undoubted examples of secondary enrichment.

Fluorite.—This mineral occurs somewhat sparingly, but its occurrence cannot be described as rare. Well-developed crystals of yellow, green, pale and deep purple or colourless fluorite occur in the Florence-Winscales ore-body in the 7th Limestone.

I have seen only one vein of fluorite in the ore field. It occurs in the David Lawn Mine. Here the vein proved to be vertical, 2 feet wide, flanked on one side by haematite and on the other by ory sandstone. The spar had a finely-granular appearance. The following is an analysis of a cross-section of the vein supplied by the Barrow Haematite Company :—

	%
Calcium fluoride . .	35
Silica	20
Barium sulphate . .	17
Metallic iron (present as haematite) . .	12

Mr. A. Templeman has found fluorite in the cores of five borings—in

[1] It is of interest to note that several of the kidneys were coated with siderite.

one case the mineral permeated 2 feet of Orebank Sandstone. A sample of this rock was supplied to Dr. J. Phemister, who reports as follows :—

The sandstone carrying the fluorspar was obtained from Barrow Steel, Boring No. 11, Cumberland, and is part of the Orebank Sandstone horizon of the Carboniferous Limestone Series. In hand specimen it is a light grey rock with yellowish streaks, and is mottled with patches of deep violet and pale green fluorite. On a smooth surface cut transverse to the bedding the fluorite is seen as thin elongated curving or angularly bent streaks which have a rough parallelism with the bedding, but may cross the latter at any angle. The streaks may be solid or may comprise a series of small lenses. They do not appear to be associated with a definite vein, nor do they themselves form a clean-walled vein network.

In thin section (E 18132) the sandstone is composed mainly of angular to sub-rounded grains of quartz, 0·05 to 0·3 mm. across, with a small quantity of clear alkali-feldspar which includes albite, microcline, and orthoclase, and a larger proportion of micaceous aggregate which may be replacing another feldspar. Flakes of muscovite, 0·2 mm. long, are common, and pseudomorphs of biotite in iron oxide are scarce. The cement is partly micaceous material, probably derived from the aggregate mentioned above, partly secondary quartz which is grown in crystalline continuity with the original sand grains. Black ore occurs throughout the rock as granules, and as irregular grains of the same size as the quartz and feldspar. Accessory minerals are zircon, green and brown tourmaline, and semi-opaque grains and squarish crystals which are probably anatase. The bedding of the rock is shown by the disposition of micaceous wisps, muscovite flakes, and ore in greater and less abundance in sub-parallel laminae. The more flaky grains of quartz tend to have their shortest axis transverse to this direction.

In the thin section fluorite occurs in minute irregular veins which cut across the bedding and send off shoots along the bedding. The former reach 2 mm. at their thickest part, while the latter are about 1 mm. wide at most. Both types wedge out quickly and no appearance of faulting or of rupture is observed in the sandstone at their termination, Fig. 1 (*b*) and (*c*), even though fluorite may reappear as small lenticles in the vein direction. Where a concordant vein is bordered by a micaceous lamina it retains its direction until the mica dies out ; the vein then tends to bifurcate and develops irregular borders. In places the presence of angular pieces of sandstone enveloped by fluorite produces the impression that the sandstone has been brecciated and infilled by fluorite, but since the enveloping vein stuff can be traced to its termination against unbroken sandstone this appearance is illusory.

From these structural observations it is concluded that the fluorite is not present as infillings of fractures, but is replacing the sandstone. The conclusion is confirmed by more detailed microscopic evidence. Strings and small patches of micaceous aggregate with and without adherent quartz are relic within the fluorite. In some cases the micaceous material can be seen to stretch across the vein and is obviously in its original position in the sandstone. A large flake of muscovite may become embedded in the vein by corrosion of the surrounding quartz grains, Fig. 1 (*a*). Fluorite is seen occasionally to penetrate across a quartz grain. That the quartz has been in a very mobile state during the introduction of the fluorite is shown by the very common development of crystal faces along the vein walls and the appearance of occasional perfect bipyramidal quartz crystals within the vein, Fig. 1 (*d*). It may be observed also that quartz grains within a vein have perfect faces against fluorite, but retain the detrital margin where this is protected by a mica film.

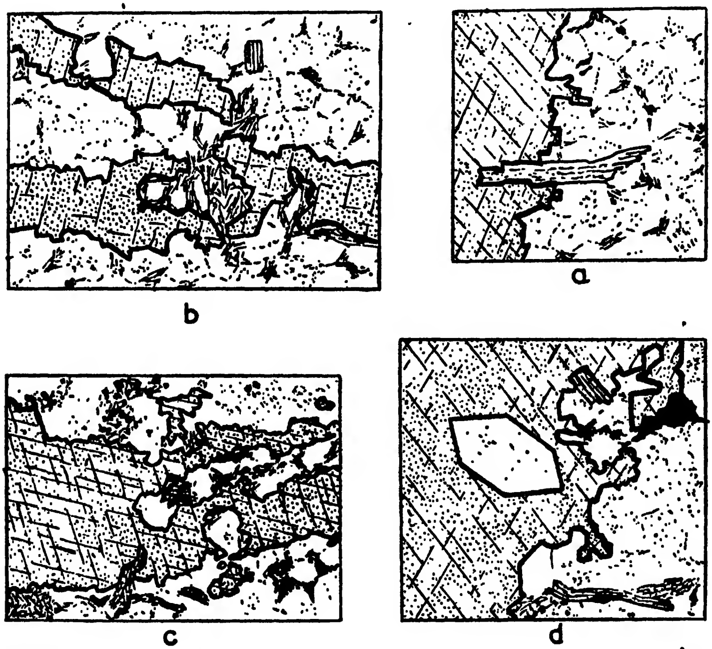
The sandstone thus provides evidence of permeation by mineralizing fluids which dissolved out the quartz of the sandstone readily, the other constituents less readily, and in their place deposited fluorite.

Fluorite has been frequently reported as a cement and as veins in sandstone, but its presence as a metasomatic replacement of quartz or sandstone is apparently not so common. Replacement of quartzite for a width of 20 feet has been mentioned by Fohs (1910), from the Susie Beeler Mine, Kentucky.

The following is Dr. J. Phemister's report on the microscopic examination of a fluorite-bearing rock from the Beckermet Mining Company's

Borehole No. 42, at a depth of 1,582 feet. The specimen is from the Borrowdale Volcanic Series, immediately under the Carboniferous Limestone. (A weathered land surface was developed on the Borrowdale Volcanics prior to the onset of Carboniferous sedimentation.)

E 18161. A compact aggregate of finely-divided clay and sericitic minerals containing ghosts of phenocrysts of feldspar. The rock is impregnated with ore as granules and as thin irregular veins which have no distinct walls. Fluorite



TEXT-FIG. 1.—Replacement of sandstone by fluorite (E 18132). (*a*) A plate of muscovite lies partly in unaltered sandstone, partly in fluorite, × 30; (*b*) and (*c*) the veins of fluorite have irregular walls and are blocked or diverted by sericite felts, × 70; (*d*) crystal faces are developed on quartz in contact with fluorite, × 100. Fluorite is represented by lines and stipple.

occupies thin veins which cut across haematite concentrations, follow cracks and haematitic strings, and form replacement veins. In places haematite builds plates within fluorite; in places it is moulded on fluorite. It is concluded that the introduction of haematite was prior to the fluorite, but that further introduction of haematite or recrystallization of that already in the rock, occurred at the time when the fluorite was introduced. A little barite is present in the fluorite veins and is idiomorphic against, therefore earlier than the fluorite.

It is submitted that the mineral assemblage taken as a whole clearly indicates deposition from magmatic solutions.

CHEMICAL CONSIDERATIONS

Whilst much of the haematite found in the Carboniferous Limestone is a metasomatic replacement deposit of limestone there is abundant evidence of direct deposition of haematite from solution. The large masses of kidney ore found in several ore-bodies, as for example in Crowgarth Mine, must have been deposited directly from solution and similarly with the occurrences of specularite. But the strongest evidence of direct deposition of haematite from solution is derived from a consideration of the haematite veins that are found, adjoining the main ore field, principally in Skiddaw Slates, but also in the Borrowdale Volcanics and in the Ennerdale granophyre and Eskdale granite. Several of these veins attain a width of 20 feet, while at least one, in Skiddaw Slates, has been followed to a depth of 600 feet. The country rock is not calcareous, so that it would appear to be impossible to regard the haematite veins as originating by metasomatic replacement of deposits of calcium carbonate. The realization that haematite deposits are formed by direct deposition from solution as well as by metasomatic replacement of limestone, leads us to a consideration of the chemical nature of the mineralizing solutions. Kendall (1893) considered that the magmatic solutions were probably of ferric chloride, and in the light of subsequent investigations on the gaseous emanations from magmatic solutions carrying ferric oxide there appears to be considerable substance in this claim.

Allen and Zies (1923) have made a chemical study of gases from the fumaroles of the Katmai Region. They found that the gases given off are H_2O (steam), HCl, CO_2, HF, and H_2S, whilst the commonest mineral lining the joints in the country rock is Fe_2O_3, from which they deduce that the following well-established reversible reaction has been operative :—

$$(1)\ 2FeCl_3 + 3H_2O \rightleftharpoons 6HCl + Fe_2O_3$$

Mineralizing solutions of this nature would account for direct deposition of haematite in the veins of the Skiddaw Slates. They fail to account for the metasomatic replacement deposits of haematite in the limestones. To explain these we must first consider an important property of $FeCl_3$—its ability to hold in aqueous solution considerable quantities of hydrated Fe_2O_3. Eighteen equivalents of hydrated Fe_2O_3 can be dissolved in one of $FeCl_3$ (Mellor, 1935, vol. xiii, p. 831). It is not necessary to consider in detail the reactions which may take place. The following oxy-chlorides are said to have been separated from a solution of the two salts: $Fe_2Cl_6.5Fe_2O_3$, $Fe_2Cl_6.9Fe_2O_3$, $Fe_2Cl_6.17Fe_2O_3$, and with treatment $Fe_2Cl_6.72Fe_2O_3$ is said to have been prepared (Mellor, vol. xiv, p. 72). Other workers do not consider that the two salts enter into chemical combination in aqueous solution (Mellor, vol. xiii, p. 835), but that Fe_2O_3 passes into colloidal solution. From our point of view the important fact is that relatively high amounts of Fe_2O_3 can be carried in solution by $FeCl_3$.

Now consider the reaction on limestone of a solution in equilibrium as represented by equation (1). An exothermic reaction results thus :

$$\begin{aligned} 2FeCl_3 + 3H_2O &= 6HCl + Fe_2O_3 \\ 6HCl + 3CaCO_3 &= 3CaCl_2 + 3CO_2 + 3H_2O \\ (2)\ \text{or } 2FeCl_3 + 3CaCO_3 &= 3CaCl_2 + Fe_2O_3 + 3CO_2 \end{aligned}$$

If the $FeCl_3$ carried additional Fe_2O_3 in solution then the continuous diminution of the amount of $FeCl_3$ by reaction with $CaCO_3$ will lead to deposition of Fe_2O_3 in excess of that represented by equation (2). Only in this manner is it possible to replace limestone by haematite volume for volume (the approximate state of affairs which exists in the ore-bodies of the Carboniferous Limestone), as this result is unobtainable from equation (2).

Here three molecules of $CaCO_3$ are equivalent to one molecule of Fe_2O_3 i.e. by weight, 300 of $CaCO_3$ are equivalent to 160 of Fe_2O_3. Taking the specific gravities of limestone as 2·7 and of average commercial ore as 4·0 the proportions by volume are 111·1 of $CaCO_3$ to 40 of Fe_2O_3, or approximately 3 : 1. Such diminution of volume is not found in the ore-bodies.

Thus it is considered that the dominant constituents of the magmatic solutions which gave rise to the iron ore deposits in West Cumberland were soluble Fe_2O_3 in $FeCl_3$.

The comparable reaction in regard to FeF_3 on limestone is :—

$$2FeF_3 + 3H_2O = 3H_2F_2 + Fe_2O_3$$
$$3H_2F_2 + 3CaCO_3 = 3CaF_2 + 3CO_2 + 3H_2O$$
$$(3) \text{ or } 2FeF_3 + 3CaCO_3 = 3CaF_2 + Fe_2O_3 + 3CO_2$$

As has been shown in the preceding section fluorite (CaF_2) and haematite (Fe_2O_3) are found in intimate association. The relative amount of FeF_3, however, in the magmatic solutions must have been small.

The presence of sulphide ores of iron, copper, and lead needs little chemical explanation since H_2S is likely to have been present among the magmatic gases as the study of the gases at Katmai suggests. There remains for consideration the occurrence of barytes. It is clear that oxygen was not in short supply in the magmatic solutions which gave rise to the West Cumbrian deposits, for the iron in the ore-bodies was deposited predominantly in the ferric oxide form, and much of the ore contains water of crystallization. Thus the deposition of barium in the insoluble sulphate form is to be expected.

Haematite and Barytes Proved in Recent Borings

During recent years scores of borings in search for ore in the Carboniferous Limestone have been sunk through thick New Red Sandstone cover, and the cores of 124 bores have been examined by officers of H.M. Geological Survey. The earlier bores were seen by Dr. B. Smith; from 1932 onwards their examination fell to Mr. A. Templeman and the writer. The boring logs cannot be published in detail, but a table may be drawn up, based on the observations of the above-mentioned officers, to indicate the distribution of the occurrences of haematite and barytes. The borings selected are those which, commencing in the St. Bees Sandstone, proved at least 500 feet of that formation, passed through the New Red Brockram and the Carboniferous Limestone, and entered the Borrowdale Volcanic Series. Borings proving less than 500 feet of St. Bees Sandstone are not tabulated. In the table the depth to the first occurrence of ory sandstone is given; and, so that the relationship of these occurrences to the Brockram and the Carboniferous Limestone may be

assessed, the depths to the top and base of the Brockram are given. Occurrences of haematite and barytes in the Brockram and the Carboniferous Limestone are also tabulated. It is emphasized that occurrences are listed without reference to thickness.

St. Bees Sandstone.—Occurrences of haematite in the St. Bees Sandstone hitherto have escaped mention. In hand-specimen an " ory sandstone " may be defined as a sandstone impregnated by haematite to such an extent that it stains the fingers, is appreciably heavier than the normal sandstone, and is dark red to purple in colour. A typical sample, taken from Beckermet Borehole No. 32, at a depth of 346 feet, was examined by Dr. J. Phemister, who supplies the following report :—

IRON ORE IN SLICED ROCK, E. 18164

In thin section the ore mineral forms a shapeless aggregate in which the individual crystals seem to be granular rather than fibrous. The aggregate is opaque except on thin margins and is then birefringent, but shows no dichroism. The streak of the ore is red. The identity of the mineral is uncertain and it is therefore referred to as limonite.

Micrometric measurement gave 36 per cent by volume of iron-ore. Assuming (i) this ore has a sp. gr. of 3·7, the specific gravity of the rock was calculated as 3·03 ; (ii) the ore has a sp. gr. of 5·2, the specific gravity of the rock was calculated as 3·57.

The actual sp. gr. of the rock, determined by Mr. C. O. Harvey, was 3·06. This result indicates either (i) that the ore mineral has a specific gravity of 3·7, i.e. it is limonite, or (ii) the micrometric estimation is too high if the ore mineral is haematite, sp. gr. 5·2.

B. Smith in *Iron-Ores—Haematites of West Cumberland*, p. 36, points out that the soft red ores, among which the mineral under study must be reckoned, may contain 13·6 per cent of water, corresponding to a composition turgite 10, limonite 90 per cent. It may therefore be accepted that the iron ore impregnating sandstone is a water-rich variety dominantly limonite. The specific gravity to be assumed for limonite is, of course, uncertain, but if the micrometric estimation be accepted as including small cavities and finely-divided material so iron-stained as to be inseparable from the ore in thin section, then the value assumed, viz. 3·7, is a reasonable one, and as shown above leads to the correct value of the bulk specific gravity of the rock.

From Analyses on p. 48 of B. Smith's memoir on *Iron-Ores*, ore with sp. gr. of 3·66 contains 60·6 per cent Fe_2O_3, 15·2 per cent moisture-loss, 25·2 per cent rest. The value 3·7 for the specific gravity of the iron-ore mentioned above must indicate a percentage of iron at least as high as in this analysis, since it is probable that the value 3·7 allows for the presence of pore spaces.

The micrometric estimation of 36 per cent iron ore by volume corresponds, the iron ore having sp. gr. of 3·7, to 44 per cent by weight of iron ore. Therefore the minimum weight percentage of Fe_2O_3, present in the sandstone, is $\frac{44 \times 60{\cdot}6}{100} = 27$ per cent, corresponding to 19 per cent metallic iron.

The iron content of this rock was later determined by Mr. C. O. Harvey as 25·9 per cent, Fe_2O_3. The agreement between the micrometric and chemical estimations is close and indicates the validity of the assumptions made in the micrometric estimation. Since the latter lead to a minimum value of 27 per cent it is probable that some of the iron-stained clay was measured as ore.

Barytes has been proved in the St. Bees Sandstone in one borehole only.

Brockram.—Although as proved by borings occurrences of haematite in the Brockram are found throughout its thickness they are more numerous in the upper and lower parts which are open-textured coarse conglomerates. The middle portion which tends to be less coarse, and

TABLE INDICATING OCCURRENCES OF HAEMATITE IN BORINGS

Boring		Depth in feet to first occurrence of oiy sandstone	Depth in feet to top and bottom of Brockram		Haematite and barytes in Brockram		Haematite and barytes in Carboniferous Limestone	
Egremont Mining Co.	No. 7	1,012	1,106	1,519	Fe		Fe	
,, ,, ,,	11	1,213	1,333	1,637			Fe	
,, ,, ,,	12	1,007	1,079	1,258			Fe	
,, ,, ,,	17	1,076	1,146	1,524	Fe		Fe	
,, ,, ,,	18		1,144	1,336	Fe		Fe	
,, ,, ,,	19		1,007	1,282			Fe	
,, ,, ,,	20		1,092	1,321	Fe	Ba	Fe	
,, ,, ,,	21	965	1,058	1,334			Fe	Ba
,, ,, ,,	22	964	1,016	1,289			Fe	Ba
,, ,, ,,	23	1,040	1,061	1,303	Fe	Ba	Fe	
,, ,, ,,	24		1,155	1,457	Fe	Ba	Fe	
,, ,, ,,	25	990	1,090	1,355	Fe	Ba	Fe	Ba
No. 1 Joint . . .	.	1,360	1,467	1,907				
Stanley . .	No. 6		1,265	1,653	Fe		Fe	Ba
,, ...	7		1,007	1,336	Fe	Ba	Fe	Ba
,, ...	8		1,195	1,522				
,, ...	9		1,089	1,433	Fe	Ba	Fe	Ba
,, ...	10		1,254	1,638	Fe		Fe	Ba
,, ...	12		916	1,201	Fe			
Beckermet . .	No. 30		1,136	1,341	Fe	Ba	Fe	Ba
,, ...	31		992	1,250	Fe		Fe	
,, ...	33		771	994			Fe	
,, ...	34		1,015	1,274	Fe	Ba	Fe	
,, ...	35	958	1,140	1,433			Fe	Ba
,, ...	36		1,185	1,426		Ba	Fe	Ba
,, ...	37		761	977	Fe	Ba	Fe	Ba
,, ...	38	756	780	987	Fe	Ba	Fe	Ba
,, ...	40	700	856	1,066	Fe	Ba	Fe	Ba
,, ...	41	648	771	978	Fe	Ba	Fe	Ba
,, ...	42	1,094	1,270	1,572	Fe		No limestone proved	
,, ...	43		637	912	Fe	Ba	Fe	Ba
,, ...	45	860	953	1,117	Fe	Ba	Fe	Ba
,, ...	46	380	512	680	Fe	Ba	Fe	Ba
,, ...	47		624	896		Ba	Fe	Ba
,, ...	48	Ba 512	520	711	Fe	Ba	Fe	
,, ...	49		861	1,057	Fe	Ba	Fe	Ba
,, ...	69		916	1,201			Fe	
,, ...	70	972	1,138	1,171	Fe	Ba	Fe	Ba
,, ...	71		575	731	Fe	Ba	Fe	Ba
,, ...	72	1,081	1,274	1,527	Fe	Ba	Fe	Ba
,, ...	73	982	1,081	1,398	Fe	Ba	Fe	Ba
,, ...	74		883	1,021	Fe	Ba	Fe	Ba
,, ...	76		1,045	1,295	Fe	Ba	Fe	Ba
,, ...	78		806	1,276	Fe	Ba	Fe	Ba
,, ...	80		1,084	1,135	Fe		Fe	Ba
,, ...	81		905	1,157	Fe	Ba	Fe	Ba
,, ...	82		565	751	Fe	Ba	Fe	Ba
,, ...	83		1,216	1,451			Fe	Ba
,, ...	84	941	954	1,253	Fe		Fe	Ba
,, ...	85		1,088	1,288	Fe		Fe	
,, ...	87		981	1,232	Fe		Fe	Ba
,, ...	88		1,067	1,324	Fe		Fe	
,, ...	89	886	914	1,223	Fe	Ba	Fe	Ba
,, ...	90	1,003	1,181	1,454			Fe	
,, ...	91		884	1,121	Fe		Fe	
,, ...	92	1,145	1,316	1,572	Fe		Fe	Ba
* ,, ...	94		1,499	1,807	Fe		Fe	
,, ...	95		1,185	1,488	Fe		Fe	Ba

* Base of limestone not reached.

in the western part of the area has a shaly matrix, is relatively free from ore impregnations. The haematite occurrences vary from heavy ore impregnations to "gravel ore" many feet thick in which matrix and limestone pebbles are wholly or partly converted into haematite. Occasionally kidney ore is developed between and around pebbles of the conglomerate.

As seen in the boring cores barytes in the Brockram occurs in veins less than 6 inches thick.

Carboniferous Limestone.—In the cores the haematite occurrences range from films lining joints ("ore joints") to solid hard blue and soft red ore up to 60 feet thick, the hard blue ore occasionally veined by specularite.

Barytes proved in the cores of the Carboniferous Limestone occurs chiefly in veins less than a foot thick, but it also occurs in intimate association with haematite, and then it usually has a pink coloration. The order of deposition of the two minerals is frequently difficult to determine, but in some specimens the barytes is seen to be later than the haematite.

Lateral Migration of the Ore-bearing Solutions

Perusal of the table on p. 77 brings out several significant points. Although occurrences of haematite and barytes in the New Red Sandstone Series bear no relationship to depth or to Ordnance Datum, a geological connection is discernible. Both minerals are restricted to the Brockram (in which they are almost equally prevalent as in the Carboniferous Limestone) and to the basal beds of the New Red Sandstone. In these holes the maximum proved thickness of the St. Bees Sandstone is 1,500 feet; there are twenty-three listed instances of ory sandstone, but all are found within 200 feet of the top of the Brockram. The main mass of the St. Bees Sandstone is completely devoid of ore traces.

If the ore deposits in the Carboniferous which underlie the Brockram be examined a further significant point emerges. The ore-bodies cluster near the base of the Brockram. The rule holds irrespective of the Carboniferous horizon directly underlying the Brockram, and the occurrences are independent of the Ordnance Datum of these deposits which range from 400 feet above to 1,500 feet below O.D. To cite examples: At Millyeat, near Frizington, a thin band of Spirorbis Limestone in the Upper Coal Measures (Whitehaven Sandstone Series) has been converted into haematite in close proximity to the base of the overlying Brockram. In the neighbourhood of Bigrigg the full sequence of the Carboniferous Limestone underlies the Brockram, and hereabouts ore-bodies are developed in the upper limestones, but fail to make in the lower limestones, as for example at Pallaflatt and Wyndham Mines, in which ore-bodies are developed in the 1st to 4th Limestones. To the south of Egremont the upper limestones were removed by denudation prior to the onset of New Red sedimentation, and in this area we find the ore-bodies under the Brockram in the 7th Limestone in Winscales, Florence, and Ullcoats Mines. It is this formidable body of evidence that Smith ably marshalled to support the theory of downward percolation of the ore solutions by meteoric waters. That it indicates descent from the Brockram cannot be gainsaid.

Thus irrespective of altitude the magmatic deposits of haematite and barytes in the New Red Sandstone are confined to the Brockram and to the immediately overlying beds; and identical deposits in the Carboniferous Limestone cluster beneath the base of that formation.

Clearly we have here a case of lateral migration of magmatic solutions in the Brockram. The solutions obtained entry into the Brockram, flowed down dip in that formation, and descended from it by means of suitable fractures into the underlying Carboniferous.

The dip of the New Red Rocks is north-westward, westward, and south-westward, away from the Lower Palaeozoic rocks of the Lake District, and it is to that area that we must look for the original source of the uprising solutions. In the Lower Palaeozoic rocks and intrusions of this mountainous area, fringing the eastern border of the main ore field, there are commercially important veins of haematite, as for example, the veins of Kelton and Knockmurton Fell, the Pillar and Red Pike Vein, south-east of Ennerdale, and Red Brow Vein, Eskdale. Additionally there are haematite veins which do not carry ore in commercial quantity. All these veins present themselves as the obvious conduits for the rising magmatic solutions.

Geographical Distribution of the Brockram in Relation to the Ore-bodies

Numerous borings in the concealed ore field south of Egremont show that from west to east Brockram oversteps successively lower horizons of the Carboniferous Limestone until it rests on the Lower Palaeozoic rocks. Thus from Haile Moor, east of Egremont, south-eastwards to Gosforth, a distance of five miles, at or near outcrop, the Brockram rests directly on the Lower Palaeozoic rocks. It is reasonable to presume a similar overstep towards the Lake District in the northern part of the ore field where the Brockram is preserved on the Carboniferous only as faulted outliers. Prior to removal by denudation of the New Red rocks (including Keuper Marls) from the Lake District uprising magmatic solutions in the Lower Palaeozoic rocks would enter directly into the New Red Sandstone, there being no intervening Carboniferous rocks. In such rocks, mainly porous in character but dry because of an impervious cover of Keuper Marls and possibly Liassic shales, flow would be down dip, particularly in the basal conglomerate, the Brockram. To the west the Brockram overlies the Carboniferous Limestone, and the solutions would gain access to that formation down fault fissures.

The Brockram, however, exercised an additional influence on ore deposition. In order to explain it it is necessary to digress somewhat to give brief details of the lateral changes which affect this rock and the associated basal members of the New Red Series.

Inland, fringing the Lake District fells, St. Bees Sandstone is directly underlain by a coarse conglomerate, the Brockram. As we travel westward the Brockram thickens to a maximum of 450 feet by the passage of the St. Bees Sandstone into Brockram. Still farther west shales develop at the top of the Brockram, and this conglomerate is split into two and sometimes three beds by thick shales, and in the conglomerates themselves thin shales appear. Still farther west the shales thicken at the expense of the beds of conglomerates, and a bed of Magnesian Limestone

makes its appearance. At the coast the lateral replacement of conglomerate by shale is often almost complete. At St. Bees, as proved in a boring, 370 feet of shales with gypsum (St. Bees Shales) and 18 feet of Magnesian Limestone overlie 56 feet of Brockram ; to the north-northwest, at Barrowmouth, the basal conglomerate is only inches to a few feet thick, and underlies 12 feet of Magnesian Limestone, which in turn is overlain by thick shales.

The oncoming of the shales in a westerly direction is rapid. By the aid of numerous borings it is possible to delimit their extension and to indicate their westerly thickening by lines of equal thickness (isopachytes), see map, Fig. 2. The map also indicates the position of the main ore-bodies, and it will be seen that the oncoming of thick St. Bees Shales coincides with the westerly limit of proved ore-bodies. In the Gosforth Memoir I suggested that these shales acted as an impervious cover to descending mineralizing solutions (Trotter, p. 70). This view needs modification. It is now considered that the lateral change in the basal New Red Sandstone from a conglomerate to a shale series had the effect of retarding and eventually stopping the westerly migration of the magmatic solutions in the Brockram. Where the St. Bees Shales are thick the existence of ore-bodies has not been proved, and of mineralization in the Magnesian Limestone there is no sign.

My grateful thanks are due to several colleagues for reading the paper in manuscript and offering useful criticisms and suggestions. I am especially indebted to Dr. J. Phemister.

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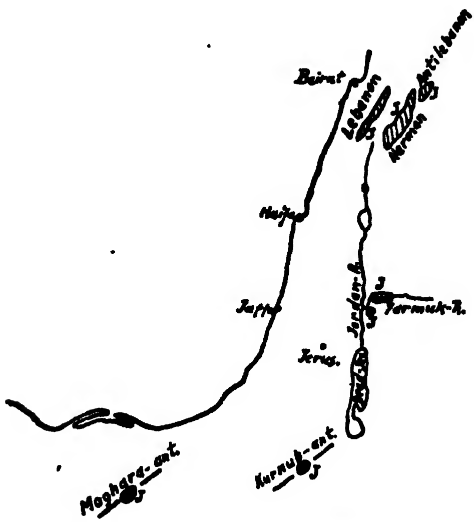
A New Jurassic Outcrop in the Jordan Valley

By M. Avnimelech

NEARLY twenty years ago L. R. Cox published (*Ann. Mag. Nat. Hist.*, 1925, p. 169) an account of "Bajocian-Bathonian outcrop in the Jordan Valley and its Molluscan Remains", which was then, according to the author, "the first authentic record of Jurassic rocks in the Jordan Valley region, or anywhere between Northern Sinai and Mount Hermon, in Syria." Miss Helen Muir-Wood in the same issue analysed the Brachiopod fauna of these rocks.

Later new Jurassic outcrops were recognized in Southern Palestine, in the Kurnub anticline, south west of the Dead Sea (Blake, 1935).



Text-fig. 1.—Sketch-map of the Jurassic outcrops (J) in Sinai, Palestine, and Southern Syria. The new outcrop referred to is situated south of the mouth of Yarmuk-River.

Strangely enough no other traces of Jurassic rocks have been found in the Jordan valley or farther east. It may be remarked that Cox's designation of the said Jurassic outcrops as situated in the Jordan valley is not altogether accurate: the outcrops are situated in the valley of Yabbok (or Wadi Zerka), an eastern affluent of the Jordan.

I recently received from B. Aisenstein, a mining engineer of Palestine, a few fossils originating from the foot of the hill on the eastern border of the Jordan valley, some 15 km. south-east of Jisr-ed-Damiye (Damiye bridge), to the south of the outcrops in Yabbok valley. The fossils are as follows:—

Cymatorhynchia (?) *quadriplicata* (Zieten). *Cymatorhynchia quadriplicata* (Zieten) var. *Rhynchonella* cf. *orbignyana* Oppel. *Eudesia cardium* (Lamarck). *Solarium* aff. *cossmanni* Bigot.

The fossils, although few, are clearly characteristic of a middle Jurassic or, more accurately, a Bathonian age, e.g. of the same age as the outcrops in the Yabbok valley. *Cymatorhynchia* (?) *quadriplicata* was found several times in the Bathonian of Yabbok valley and in the Bathonian of Jebel Moghara in Sinai, but has not yet been found in the Jurassic of Mount Hermon or of other areas in Anti-Lebanon. *Eudesia cardium* is mentioned also from Sinai and Yabbok valley only. *Rhynchonella orbignyana* is common in the Callovian of Jebel Moghara but also occurs as low as the Bathonian. We have in our possession only two specimens of this fossil, and it is therefore undesirable to discuss it in more detail. The *Solarium* is fragmentary, and resembles in ornamentation and general shape *S. cossmanni* Bigot from the Bathonian of Normandy, but is nearly twice as large as the later.

The rock containing the fossils consists of a compact brown limonitic and calcitic limestone with unrecognizable microscopic fossils and many fragments of mollusca and brachiopoda. It occurs in a series of beds at least 20 metres thick, lying on a formation of brown "Nubian" sandstone of continental origin and desert facies. The Bathonian beds are covered by marly limestone of Cenomanian age. Thus the Bathonian stage is here the sole representative of marine Jurassic; the whole of Lower Jurassic up to Bajocian and the whole of Upper Jurassic as also the Lower Cretaceous are missing here.

The incompleteness of marine Jurassic in the Yabbok area is surprising in view of the well represented Middle and Upper Jurassic in Sinai and in the Kurnub anticline in Palestine, as also in the Hermon and in the entire Anti-Lebanon. In Sinai the Jurassic transgression begins with the Bajocian, persisting up to the Oxfordian at least; in the Kurnub anticline occur beds from the Bajocian up to Sequanian (Blake, 1935); in Hermon, above a lacustrine formation probably of Liassic age, there exists a very thick series (of more than 1,300 m.) from the Bajocian up to Kimmeridgian-Tithonian stage. The structure of the Yabbok area has already been determined by G. S. Blake (1935, 1939) as a dome, and the coincidence of this structure with very incomplete marine Jurassic is evidently not accidental.

In connection with this problem it is of interest to quote the conclusions of Vautrin (1934) as to the Jurassic of Hermon and of Anti-Lebanon. He states: "La succession stratigraphique continue du Bathonien au Kimmeridgien ne se rencontre que dans l'extrémité méridionale (of the Hermon), entre Arné et Medjdel Chems. En s'éloignant vers le Nord, une lacune, dont l'amplitude va croissant, apparaît dans la série au dessus du Callovien inférieur. C'est ainsi que dans la région de Rachaya et de Yenta, les marnes du Lusitanien, où abondent les coraux, reposent directement sur les calcaires massifs de l'Oolithe inférieur; tandis que dans l'extrémité septentrionale du massif jurassique, entre Zebdani et Sergaya, c'est le niveau supérieur à *Balanocidaris glandifera* (Kimmeridgien) qui repose par l'intermédiaire d'une brèche sur les calcaires massifs du Bathonien et du Callovien inférieur."

In a supplementary paper Vautrin (1934a) concludes: "La lacune stratigraphique présentée par la série jurassique dans l'Anti-Liban, au Nord du massif de l'Hermon, semble témoigner de mouvement à la fin

de l'Oolithique inférieur, ayant provoqué une prémière surrection de ce massif. Sur le versant Nord-Ouest de l'Hermon, près de Rachaya el Fokkar, les grès néocomiens reposent sur les calcaires de l'Oolithe inférieur par l'intermédiaire d'une brèche formée d'élements empruntés uniquement à cet étage. Ceci semblerait prouver que la transgression lusitanienne dont on rencontre les dépôts au Nord de l'Hermon, laissait encore partiellement émérgé le massif."

It seems then very probable that the incompleteness of the Jurassic in the Yabbok structure is connected with a similar historical development, i.e. with the beginning of uplift. No doubt the uplift of this dome began (perhaps also was completed) in Callovian times.

The formation of this dome has influenced both structurally and stratigraphically wider areas to the west: on the other side of the Jordan valley there exist the oldest formations of Central Palestine, belonging to Albian-Aptian stages of Lower Cretaceous.

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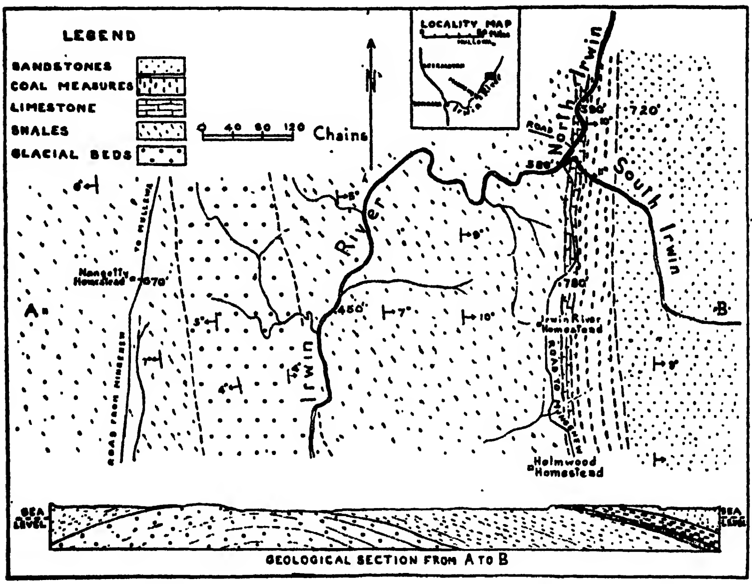
Heavy Minerals in the Irwin River Coal Measures, Western Australia

By Dorothy Carroll, University of Western Australia

Introduction

THE area covered by Permian formations in the vicinity of Irwin River, Western Australia (see Text-fig. 1) has been visited many times by members of the Department of Geology, University of Western Australia, with parties of students for field instruction in mapping.



Text-fig. 1.—Sketch map showing Permian rocks in the Irwin River section.

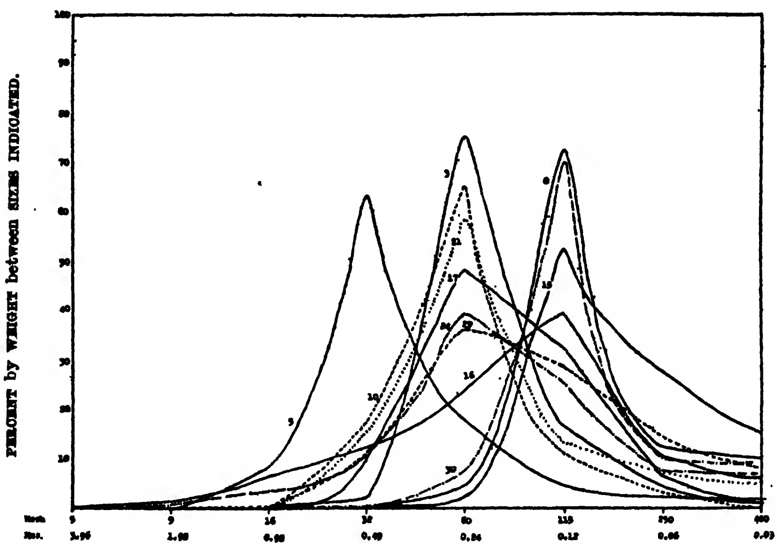
In 1939 the author collected a suite of specimens from the principal beds of the Coal Measure Series for heavy mineral investigations, the results of which are recorded in this paper.

The Permian sediments at the Irwin River have been divided into the following formations (Woolnough and Somerville, 1924; Raggatt, 1936) in descending order :—

	Thickness in feet.	
Sandstones and Shales (Upper Marine)	300	Middle
Coal Measures	250	Permian
Limestones (Fossil Cliff Beds) . .	75	Lower
Shale and Glacial beds . . .	1,520	Permian

These formations have been folded into a gentle anticline with the axis trending approximately north-south; they rest on an eroded basement of Precambrian rocks. In the valley of the North Irwin, with which this paper is principally concerned, there is a complete section through the Coal Measures which dip at about 10° to the east. Elsewhere the dips are rather less and the glacial beds in the centre of the anticline dip at 4° and 5° respectively. Papers giving details of the stratigraphy are now being prepared by others.

In the North Irwin the Coal Measure Series is about 250 feet thick as measured by Raggatt (1936) and by students of the University in 1939. The section in the South Irwin (see Text-fig. 1) has been less reliably measured as the exposures are not so good. Correlation of particular



GRAIN-SIZE.

TEXT-FIG. 2.

beds in the South Irwin section with those in the North Irwin section has been rather difficult, for the beds tend to thin out along the strike. This investigation shows that the heavy residues are helpful for such correlations. The lower part of the Coal Measures in the North Irwin consists principally of sandstones, the coal seams and carbonaceous shales with several plant-bearing horizons (Teichert, 1939) occurring in the upper 50 feet or so. The coal seams at the Irwin River were the first to be discovered in Western Australia, but the coal is of poor quality and has little if any commercial value.

Table 1 gives the details of the Coal Measure section in the North Irwin and the stratigraphic position of each specimen examined. The positions of the specimens from the South Irwin section are given for comparison. The thickness of each bed is that measured in 1939, and

TABLE I

STRATIGRAPHY OF THE NORTH IRWIN SECTION

Specimen Number. South Irwin.	North Irwin.	Description of Beds.	Thickness. ft.	in.	Name.
		Shale			
		Sandstone			
		Shale	8	0	Upper Marine
	20	Sandstone + Fe bands	2	0	
		Jarosite shale	4	0	
	19	Sandstone		6	(Worm Track beds)
		Jarosite shale	2	6	
	18	Shale	9	0	
26	17	Gritty sandstone	14	0	
25	16	Current-bedded sandstone	2	0	
		Shale (Sphenophyllum)	2	0	
		No. 3 Coal seam (or carb. shale)	3	0	
		Sandstone + Fe bands	11	0	
? 24	15	Sandstone	6	0	
		Shale	1	6	
		No. 3 Coal seam	4	6	
		Sandstone	4	0	
		Carbonaceous shale	2	0	
	14	Sandy Shale	4	0	
		Sandstone	3	0	
23	13	Argillaceous sst.	17	0	Coal Measures
		Shale	25	0	
		Sandstone	1	6	
		No. 2 Coal seam	4	6	
	12	Gritty sandstone	1	6	
? 22		Shale	1	0	
		Sandstone	1	6	
		Shale		6	
		Sandstone	1	0	
		Shale	1	6	
		Sandstone	1	6	
		Shale	3	0	
		Sandstone	28	0	
		No. 1 Coal seam	9	0	
		Sandy shale	2	0	
		Carb. shale	1	0	
	11a, 11, 10, 9	Sandstone	28	0	(High Cliff beds)
		Grit or fine congl.	6	0	
21	8	White sandstone	56	0	
	4, 5, 6, 7	Current bedded sandst.	8	0	
	3	Fine white sandstone	15	0	
	2	Blue micaceous shale	13	0	
		Ferrugineous sandstone	4	0	Fossil Cliff beds
	1	Fossil Cliff limestone	43	0	

although the section is rather detailed it agrees essentially with that of Raggatt (1936). The beds are given in descending order.

Laboratory Procedure

Each specimen was carefully disintegrated in order to free the individual grains but not to break them; this was readily accomplished as most of the sandstones were loosely consolidated with somewhat argillaceous binding material. Mechanical analyses were made of a number of the sandstones by sieving through a set of Tyler screens; the results are shown in Text-fig. 2, which will be commented upon in a later part of the paper.

Only the finest grades were used for bromoform separations; where a mechanical analysis has been made the + 115 or + 250 (Tyler) grade was used; but where there was no mechanical analysis the material passing through an 80 Tyler sieve was used after the finest clay grade particles had been washed out. The heavy residues were fairly large in most specimens, but unfortunately were not weighed so that comparisons are difficult.

The Heavy Residues

The Mineral Assemblages

The heavy residues contained the following suite of minerals: limonite (very abundant), ilmenite, magnetite, purple and colourless zircon, garnet, tourmaline, staurolite, kyanite, sillimanite, epidote, spinel, mica, chlorite, amphibole, sphene, monazite, derived and authigenic rutile, authigenic anatase. Of these minerals, apart from the ubiquituous opaque grains, zircon, garnet, tourmaline, and rutile are present in greater quantities than the remaining minerals. Kyanite, staurolite, and epidote are often conspicuous.

The distribution of these heavy minerals is given in Table II.

Before giving detailed descriptions of some of the minerals it will be seen from Table II that there are several features of interest in the distribution of minerals in these residues. The most striking feature is the "flood" of garnet in specimens 13 and 14 which were collected just below the 3rd Coal seam in the North Irwin Section and in specimen 23 from between two coal seams in the South Irwin section (see Table I). The specimens, evidently coming from the same horizon, provide a most valuable "marker bed" for future correlations in the area. The beds of the High Cliff Sandstone also have a number of distinguishing features, the most important of which is the small proportion of non-opaque grains to opaque grains in these residues. Another feature is the marked rounding of the grains in contrast to the angularity of grains in specimens higher up in the series. Specimens from the Worm Track Sandstones show an increase in the non-opaque minerals and the same suite is present in both the North and South Irwin sections.

Notes on the Individual Minerals

Zircon is one of the most interesting minerals in these assemblages, as it occurs in both coloured and colourless varieties.

Where there is an abundance of purple grains there is a decrease of

colourless zircon. This is most marked in the residues from sandstones of the High Cliff beds, where the principal zircon is coloured, and the Fossil Cliff Limestone and the Worm Track Sandstone, where purple coloured zircon is in the minority.

The coloured grains vary from tawny to deep pinkish purple; the latter are strongly pleochroic and are similar to the coloured zircons in

TABLE II

HEAVY MINERALS IN THE COAL MEASURES, IRWIN RIVER

Specimen Nos. descending order, stratigraphically.		*Ilmenite.*	*Limonite.*	*Magnetite.*	*Zircon.*	*Garnet.*	*Tourmaline.*	*Staurolite.*	*Kyanite.*	*Sillimanite.*	*Rutile.*	*Epidote.*	*Amphibole.*	*Chlorite.*	*Mica.*	*Sphene.*	*Spinel.*	*Monazite.*	*Anatase.*
North Irwin.																			
20	Upper	+	A		P	S	+	+	+		+	S				S		+	
19	Marine	+	A		A		+	+	+		+	+				S			
18		+	+		A	F	S	S	S		+							S	
17		+	A	+	P	+	+		S				S}		+				
16		+	A		P		F				+				+				
15		A	+		P		+	S	F		F	S			+			S	
14	Coal	+	+		+	A	S	+			+				A				
13	Measures		+		+	A	+				+	S			+				
12		+	A		A	+	+				F					S			
11a		+	A		P	+	+	+	S		+						S	S	
11		+	A		A		+	S	+		+	S							
10		+	A		S		+		+	S	+	+							
9		+	A		P		S		S		S	S				S			
8		+	A		P		F	S			F	S						S	
7		+	A		P	S	S	S			S	S							
6		+	A	+	P	S	+	S			+								
5		+	A		P		+				+	+				+			
4		+	A		A		F	S			F	S	S			S		S	
3	Fossil Cliff	+	A	+	P	+	+				+	+	S	S		+			
2	beds	+	A		P	F	+				+								
1		+	A	+	P	S	+	S			+			S			S		
South Irwin.																			
28	Upper	+	A		A	S	S	+	S		F	S				S		S	
27	Marine	+	A		P	S	+	S	S		+					S		S	S
26		+	A		A	F	S	S	F		P					S			
25		+	A		A			S	S		+	S				S			
24	Coal	+	A		A	S	+	S	S		+	S				S		S	
23	Measures	+	+		+	A	+		S		+								
22		+	+		P	S	+				+	S	S						S
21		+	A		P				S		+					S			
Other Species.																			
29	Coal	+	A	+	P	+			S		+					+			
30	Measures	+	+		A		+				+					S		S	

A = abundant; P = plentiful; F = fair amount; + = present; S = one or two grains only.

the Cretaceous beds at Gingin. Some of the lighter coloured grains are finely zoned, but usually purple zircon is robust, well-worn, and contains inclusions which are of the " bubble " variety and not rod-like. Occasionally fresh unworn grains are also seen. It is presumed that this zircon is derived from the Precambrian gneisses and meta-sediments of types similar to those in the Chittering Valley.

The colourless zircons are usually small, rounded, prismatic grains, showing occasional zoning and nearly always with small inclusions. In some beds large rounded colourless zircon occurs but generally the grains are small.

Garnet. In residues where garnet occurs only as odd grains it is colourless and somewhat rounded, but where it makes up about 95 per cent of the residue, as it does in specimens 13, 14, and 23, it is in sharply angular, often acicular fragments of a pale pink or brownish pink colour. It is evident that the agents of erosion and deposition at that time either had access to a new source of material near by or, as suggested by the angularity, that there was a return to glacial conditions.

Rutile. The grains are generally deep reddish brown in colour and of worn prismatic habit. Authigenic rutile was found in the residues from shales where the grains were bright yellowish brown and euhedral. A little anatase sometimes accompanied this authigenic rutile.

Tourmaline occurs throughout these residues in angular broken prismatic grains, and occasionally in well-rounded almost spherical grains. A pinkish grey type is prominent in some residues and small grey prisms are a feature of the finer sediments. Brown and grey grains are the commonest and there are very occasional blue grains.

Of the remaining minerals kyanite and staurolite are the most persistent, but except in the Worm Track beds they are not present in greater quantities than one or two grains per slide. Kyanite occurs in typical worn and rather angularly broken grains lying on the (100) cleavage face. Staurolite is less plentiful than kyanite and the majority of the grains are thin broken fragments few of which show any signs of rounding.

The other minerals listed in Table II show no individual characteristics and are in such small quantities that no further comment is necessary, except perhaps for monazite, which seems to be more plentiful near the top of the Coal Measure Series than at the bottom ; it is always in small well-rounded grains.

Light Fractions

Although this paper is principally concerned with the heavy minerals the light fractions from the bromoform separations were also examined, and it was found that quartz and felspar are present in about equal quantities, so that many of the sandstones should be termed felspathic sandstones. The quartz grains are generally sub-angular to angular, and there are few rounded ones except in certain beds. Microcline, orthoclase, and oligoclase occur in most of the specimens as angular fresh to somewhat weathered fragments. Muscovite is a constituent of some of the sandstones, particularly Nos. 13 and 14. Chloritic and ill-defined argillaceous grains occur in some specimens.

Mechanical Analyses

From Text-fig. 2 it can be seen that most of the sandstones are well-graded, and on comparison with Wentworth's histograms (1932) it is found that these analyses fall into the fluviatile or estuarine types.

The mechanical analyses fall into three distinct groups :—

A. A coarse sandstone with the maximum at 32 mesh (approx. $\frac{1}{2}$ mm. grain diameter) which is only represented by specimen 5, the current bedded sandstone at the base of the Coal Measure Series. .

B. Medium grained sandstones with the maximum at 60 mesh ($\frac{1}{4}$ mm. grain diameter) which includes several sandstones, e.g. Nos. 3, 10, and 21, the former being of the Fossil Cliff beds and the latter two in the Coal Measure Series.

C. Fine sandstones, with the maximum in the 115 mesh (approx. $\frac{1}{8}$ mm. grain diameter). Nos. 8 and 30 are from the High Cliff beds and No. 15 is from the top of the section not far below the Upper Marine beds.

The remaining analyses are of less well-sorted material. The diagram also shows that there is a considerable quantity of fine material which can in part be accounted for by the breaking down of such grains as weathered felspar, but which is due in the main to the argillaceous binding between the grains. Generally speaking the beds towards the top of the Coal Measures are not so well sorted as those laid down at the base when, according to Woolnough and Somerville (1924) conditions were changing from marine or estuarine to fresh-water lacustrine.

Significance of the Detrital Minerals

Although no percentage figures for the composition of the heavy mineral assemblages were obtained it is evident from the slides and from Table II that there is a definite change in these assemblages in some of the beds. The most striking of these changes is that found in the residues from specimens 13 and 14 (see Table I) sandstones from between the second and third coal seams in the North Irwin section. As a similar assemblage was obtained from a sandstone between two coal seams in the South Irwin section, some one and a half miles away, it appears that there is a definite lateral persistence of mineral suites which is helpful for correlation purposes. It remains for future investigations to prove whether these mineral assemblages persist over greater distances. The assemblage obtained from the Worm Track beds in the North Irwin section also persists laterally to the South Irwin section.

Table II shows that the heavy mineral assemblages are predominantly granitic or gneissic in character. The scarcity of non-opaque minerals in the assemblages from specimens 4 to 11 from the base of the Coal Measures (see Table I) and the roundness of the grains suggests that some pre-existing sediment may have been eroded and incorporated in these sandstones, which also contain material from newly weathered gneiss or granite in the shape of abundant felspar in some of the beds. The presence of prismatic tourmaline rather than rounded spherical tourmaline supports this statement. Worn, purple zircon grains cannot with safety be used as a criterion of much wear and transport, for many Precambrian gneisses contain similar grains.

Few if any greenstones could have been present in the eroded area, for the assemblages are lacking in amphibole, and epidote occurs only as odd grains. Tourmaline and sphene indicate granites, and so does much of the zircon, except the purple variety, which as mentioned above, probably came from gneisses, as investigations of the accessory minerals of gneisses and quartzites of the Jimperding Series (early Precambrian) have shown that it is the most prevalent type of zircon present.

With the exception of garnet, which is the major constituent in three of the residues, the metamorphic minerals only occur in very small quantities throughout the series of specimens examined, thus indicating that metamorphic rocks were not abundant in the eroded terrain. A garnetiferous schist or gneiss probably provided the abundant garnet in the thin bed represented by specimens 13, 14, and 23. The sudden influx of this garnet together with its sharp angular character indicate a definite change in conditions of deposition, and indicate that streams from glaciers supplied the material for this bed. Beds stratigraphically above show an increase in the proportion of non-opaque to opaque minerals, and the grains are angular rather than rounded as they are in the basal beds of the Coal Measures. Woolnough and Somerville (1924, p. 108) considered that " there is evidence of continued glacial action contemporaneous with coal deposition ". The heavy residues confirm this statement and show just when a renewal of glacial conditions took place.

The mineralogy of the Fossil Cliff Beds differs slightly from that of the overlying Coal Measure beds in the quantity of non-opaque minerals and also in the more angular shape of the individual grains.

The eroded land surface which provided the material for the sediments considered in this paper possibly lay to the east in the Precambrian shield. Boulders in the Glacial Beds (see Table I) are thought by Woolnough and Somerville (1924) to have come from the south-east. The Precambrian in the south-east or south could provide the detrital minerals such as have been described for the Coal Measures, and because of the rock types involved it seems likely that one source at least was in the belt of metamorphic rocks near the western edge of the Precambrian shield.

The detritals of the upper part of the Coal Measures and of the lower part of the Upper Marine (Worm Track beds) suggest that a western belt of rocks, now only visible in the Geraldton district (Lat. 28° 44′ S., Long. 114° 40′ E.) and lost by down-faulting, may have been responsible for the influx of garnet, for garnetiferous gneisses are very prominent in this district.

The most important of the detrital minerals in this series of sediments are purple zircon and garnet. The full significance of the presence of these two minerals cannot be assessed at present, but the diminution of purple zircon in beds above the flood of garnet suggests that there was no more material from the previous distributive province, which may have been to the south-east. The little that is known of the accessories in the gneisses of the western belt of Precambrian rocks indicates that colourless rather than purple zircon would have been contributed and that garnet is to be expected. Further investigations along these lines

with other members of the Permian succession may yield information which will assist in the palaeogeographic reconstruction of this part of Western Australia in Permian times.

ACKNOWLEDGMENTS

My thanks are due to Mr. F. A. Williams, now in Malaya, for the help he gave in the routine examination of the suite of specimens described in this paper, and to Professor E. de C. Clarke for permission to use the map as Text-fig. 1.

This investigation formed part of the research programme of the Commonwealth Research Grant to the University of Western Australia for which grateful acknowledgment is made.

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REVIEWS

VOLCANOES AS LANDSCAPE FORMS. By C. A. COTTON. pp. 416, with 223 figures. Whitcombe and Tombs, Ltd., 1944. Price 32*s*. 6*d*.

The object of this book, as implied in the title and stated in the preface, is the study of volcanic phenomena from the point of view of geomorphology. Nevertheless the treatment is not by any means wholly descriptive. Part I, comprising the first six chapters, is entitled "The Mechanism of Volcanism" and this, though it only runs to 69 pages, gives a very clear account of the most modern ideas as to the physics and chemistry of vulcanicity, while the second part, about five-sixths of the book, deals mainly with the morphological side of the subject, though here, too, the treatment is genetic, discussing origins as well as forms.

There are many classifications of volcanoes; however, as is here strongly emphasized, the most fundamental distinction is into lava volcanoes and fragmental volcanoes, due respectively to more or less quiet outwelling of lava, and to explosive ejection of broken-up material. It is here also stressed that the last-named type is by far the most abundant. For

example, the volcanic chain of the Sunda arc includes hardly any lava, whereas the great basalt volcanoes of Hawaii very rarely explode, in the sense of ejecting solid material on a large scale, although there is plenty of explosive activity inside the craters and in the feeding pipes. This distinction depends mainly on the chemical composition of the magma concerned, regarded as controlling the viscosity of the lava. According to recent ideas the degree of viscosity depends mainly on the percentage of iron in the magma, and this is just common sense in the light of our knowledge of the effect of even small percentages of iron in refractories. All this amounts to saying that basalt magmas form lava cones, and more acid magmas lead to fragmental cones, or as they are commonly called, ash cones.

This word, ash, suggests two reflections : first, the curious persistence of the old idea of combustion in volcanic nomenclature, e.g. *ash*, *cinders*, as well as the fundamental word *igneous* in petrology in general ; and secondly the need here, as in so many branches of geology, of a real definition of terms : for example, what is a tuff and how does it differ, if at all, from a volcanic ash ?

Since the only active craters which can really be examined in any detail are all basaltic, it follows that much of the theory of vulcanicity is founded on the study of basic lavas and their formation. In this modern theory the key-word is *gas*, which of course is to be taken as including water vapour. Professor Cotton very naturally bases his discussion to a large extent on American work in Hawaii, especially on that of T. A. Jaggar, who holds that basic magma in depth, where all the gas is in solution, is not really a mobile liquid, but may be regarded as possessing some degree of rigidity. When it comes near the surface and pressure becomes less it is vesiculated by gas escape and becomes almost frothy : it is at this point that explosive activity comes in and enormous heat is set free, partly by reactions between escaping gases, so that, as I understand it, the lava in the crater may be hotter as well as lighter than that in the pipe below, and therefore more mobile. Eventually of course a crust is formed, part of which sinks, since, as cannot be too often emphasized, frozen silicates, unlike ice, are heavier than the liquid. It may be noted here that Jaggar's magma in depth, hypomagma as he calls it, sounds very much like Daly's vitreous basaltic layer.

It is unnecessary here to discuss how lavas can burst through the cone or slop over the rim of the crater and run down the sides, to a degree depending on their viscosity. It appears that the viscosity of basalt, as compared with that of water, has been very incorrectly estimated : it is in reality enormously greater, perhaps a million times, instead of something under a hundred.

One of the most interesting subjects discussed at some length in this book is the Pelean type of eruption. The simplest explanation seems to be that a solid skin or carapace forms over the lava in the crater, forming a dome (tholoid, from θόλος, a dome), while all the while gas reactions of the kind before outlined are going on underneath it. Eventually the crust or some part of the cone gives way and the whole thing gushes out as what is commonly called a *nuée ardente*. It is to be wished that somebody would find a good English word for this, which tends to become

tiresome on constant repetition. Would sand-blast do ? I am afraid this is not original.

A whole chapter devoted to Vesuvius is also of great interest, being largely founded on Perret's work. It is sufficiently up to date to include a brief reference to the eruption of March, 1944. It is tentatively suggested that the difference between the behaviour of Vesuvius and that of, say, Kilauea, may be due to the higher percentage of potash in the magma of the first-named.

Professor Cotton makes a good point when he suggests that students of granitization in the modern sense would do well to devote some attention to the phenomena of vulcanicity, since after all the basis of their theories in the last analysis is pneumatolysis, and their *emanations* must be much the same as the highly active volcanic gases as here visualized, with the exception that at plutonic depths they cannot explode.

This review, already much too long, has so far only dealt with six chapters out of eighteen (69 pages out of 401) ; hence it is obvious that the rest of the book cannot be dealt with on the same scale. But in any case this would be unnecessary because as before stated the treatment is more descriptive, giving most readable accounts of things seen in many parts of the world, though in nearly every case causes are dealt with as well as effects. The author is indeed fortunate in having in his own island so many wonderful examples of at least two of Davis's " geological accidents ", glaciation and vulcanicity, and it is obvious that he has himself seen much in other parts of the world.

Among so much that is good I would venture to suggest that the least satisfactory part is the treatment of fissure eruptions and basalt plateaus. I think few British geologists will now be found to believe in the so-called Thulean plateau, as described on page 97, as extending continuously from Antrim to Greenland. It is not possible to detail the evidence here, and it was discussed by myself in an essay-review in the *Geological Magazine* for 1931, based on the then recent *Memoirs* of the Geological Survey. A supposed continuity of the plateau from Antrim to Mull, over Jura and Islay, presents an interesting problem in tectonic gymnastics, which may nevertheless not be beyond the powers of alpine geologists and their disciples.

For the benefit of readers who fight shy of petrology it may be added that there is not a single petrographical description in the book, and almost the only rock-names mentioned are basalt, andesite, and rhyolite : pumice is apparently applied to any highly vesicular material. *Perilith* (Jaggar) seems a rather unnecessary pedantry for wall-rock, and *clastolithic sedimentation* is rather a pompous description of block-sinking, but Professor Cotton is not responsible for these : he only quotes them.

The illustrations are numerous and excellent, and there are practically no misprints. The get-up of the book is good, but the price is high.

R. H. R.

REPORT OF THE SOIL CONSERVATION COMMITTEE, SUDAN GOVERNMENT. 4to, pp. 174, with maps. McCorquodale and Co. (Sudan), Ltd., 1944.

It is one of the paradoxes of geology that the most violent type of water erosion, leading to destruction of soil, often takes place in arid regions. This is due to a combination of circumstances, one of the most important being the concentration of the rainfall into rare downpours of extreme violence. This leads to sheet erosion and gullying. But besides the climatic factor there are numerous other causes, many of them due to man's activities, also contributing to the loss of soil, such as deforestation, over-cultivation, over-grazing, fires, accidental or deliberate (grass-burning), and so on. Nearly everywhere the goat seems to come in for special blame as highly destructive to almost all kinds of vegetation. The Sudan apparently suffers from most of these troubles, and the publication under review is the Report of a Committee set up by the Government to advise on them and to suggest remedies.

As to climatic conditions, it is well known that neighbouring areas, especially Kenya and Uganda, show evidence for the occurrence since the Pliocene of alternating dry and wet periods of decreasing intensity now correlated with maxima and minima of the Glacial Period. In the Sudan, however, it seems that there has been no variation of climate for the past 4,000 years at least, except for a slightly damper period about 850 B.C. The sheet-erosion type of denudation seems to be of some importance in the Red Sea hills, but not elsewhere. In the rest of the country loss of soil is mainly due to the other controllable causes, and the Report is largely taken up by details as to these: it appears that every district has to be treated on its own merits and no general summary can be given.

CORRESPONDENCE

UPPER SILURIAN GRAPTOLITE ZONES

SIRS,—I feel it is desirable to clarify one or two further points arising from Dr. Elles' recent letter to the *Geological Magazine* on Ludlow graptolites.

(1) The prolific haul of shelly fossils which the monotonous Central Wales Ludlovian has yielded successively to Dr. Straw and myself seem to provide a basis for correlating the sequence at Builth with that in Clun Forest. The major succession of species maxima is recognizably similar in the two areas, despite the fact that the lithological variations at Builth are anything but paralleled in Clun Forest. Furthermore the graptolite sequences in the two areas have much in common. Difficulties result only when the detailed graptolite assemblages are referred to the existing zonal framework.

(2) In referring to a " spinose group of the *M. chimaera* type " I did not wish to imply any limitation of range. Doubtless it can be justifiably claimed that " strata yielding mainly spinose graptolites of the

M. chimaera type " represent the whole or parts of the zones of *M. scanicus* and *M. tumescens.* Nevertheless the delimitation of these two zones in the field is a matter of extraordinary difficulty in Central Wales, even though it is reasonably certain that the Ludlow sequence there is complete. The alternative suggestion put forward in my previous communication is essentially a simplification for field usage in that part of the country. There are, however, certain other anomalies in regard to the occurrence of several graptolites characteristic of the zones of *M. scanicus* and *M. tumescens.* At Kerry, for instance, an horizon which has yielded *M. tumescens* in abundance lies *beneath* strata which have yielded *M. colonus, M. uncinatus* var. *orbatus* and *M. uncinatus* var. *micropoma,* typical *nilssoni* zone species (see Dr. Elles' list of assemblages). In another instance a considerable number of fragments of *M. scanicus* were obtained in soft mudstones from one locality, which also yielded recognizable fragments of *M. crinitus,* and which lay very nearly at the same horizon as the one just mentioned yielding *M. tumescens.* It is such anomalies as these which are so puzzling in the field and so difficult to reconcile with the zonal assemblages listed by Dr. Elles.

(3) The proximal dorsal curvature of *M. clunensis* ; is this feature the result of preservation ? I have already made certain observations on this point, but perhaps the following amplification should be given.

The first specimens of *M. clunensis* came to my hand in 1935 while systematically collecting from the middle part of the Wilsonia Grits along Drefor Dingle. Closer examination in the laboratory confirmed the impression that here was a new and readily recognizable Ludlow type. Two years later, while systematically collecting from the middle part of the Wilsonia Grits in the River Lugg section, ten miles south of Drefor Dingle, another band yielding *M. clunensis* was discovered. The characteristic swing of the polypary in every specimen immediately caught the eye. Some time later Dr. Straw allowed me to run through the graptolites collected from Builth. Disregarding locality numbers I picked out two specimens which were obviously closely similar to the new type. Both specimens proved to be from the same locality, in the Pterinea Beds, a similar shelly horizon to that at which the graptolite occurs in Clun Forest. Since the discovery of *M. clunensis* in the River Lugg section other localities where it is fairly prolific have been discovered on the south side of Clun Forest. Moreover it would be possible to collect from one of the good localities just so many specimens as one had the mechanical means to unearth, *all* showing the characteristic proximal swing. Specimens may also be mounted and viewed from both sides, thereby losing none of their striking dissimilarity from *M. salweyi.*

It is less important to decide whether *M. clunensis* should be regarded as a new species, a new variety of *M. chimaera,* or a new variety of *M. chimaera* var. *salweyi,* than that its existence, characters, and horizon should be put on record. The possibility of it being a multitudinously repeated freak of preservation appears to be remote.

John R. Earp.

28 Sandhurst Avenue,
Manchester, 20.
25th December, 1944.

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A Graptolite Lineage from North Cardiganshire

By JOHN CHALLINOR

1. PRELIMINARY STATEMENT

AS the result of examining a considerable number of specimens belonging to the species *Monograptus fimbriatus*, *M. raitzhainiensis*, and *M. triangulatus* from certain strata of Llandovery age at a locality in North Cardiganshire, the writer is led to the conclusion that the forms comprised within these species constitute a continuously graded morphological series ; and that the stratigraphical occurrence of these forms shows that this series is, further, an evolutionary lineage.

2. LOCALITY AND HORIZONS FROM WHICH THE SPECIMENS WERE COLLECTED

All the specimens were collected at one locality in the gorge of the River Rheidol, near the village of Pont-erwyd, in North Cardiganshire. This locality, about 25 yards long and 5 yards wide, is part of an irregular rocky ledge along the right (west) bank of the river, and is precisely indicated by O. T. Jones (Jones, 1909, p. 488, and pl. xxv). It includes his fossil localities F 15 and F 16, and the corresponding horizons are the bands (2) and (4) in his table (p. 488). The beds dip at about 30 degrees, obliquely downstream and away from the river.

Band (2) is the "*Triangulatus*-var.-band", and (4) the "*Triangulatus*-band" of the zone of *Monograptus communis* in Jones' classification of the whole succession (p. 468). The other two neighbouring fossil localities, F 17 and F 18, where the *magnus* and *leptotheca* bands are said to crop out, are now difficult to trace exactly ; all the fossils collected in recent years from this particular rocky ledge having been found at the other two spots, which thus together make one well-defined fossil locality.

In the *Monograph of British Graptolites* (Elles and Wood, 1912) the locality is frequently cited, and is given as "Rheidol Gorge, 420 and 430 yds. S.S.E. of Bryn-chwîth Farm, Pont Erwyd".

Owing to the nature of the exposure there are only certain parts of the bands (2) and (4) that can be collected from satisfactorily. These parts, each about a foot in thickness, and numbered 2*a*, 2*b*, 2*c*, 2*d*, and 4 are shown in the following table ; measurements being given above the base of band (2). As it was desirable for statistical purposes to have a reasonable number of specimens from each horizon searched, collecting was confined to these five thin bands. It may be mentioned that the

shelly fossils, which form a peculiar feature of band 2*d*, have been described by the writer in a previous paper.

4	.	26 ft. to 27 ft.
2*d*	.	13 ft. 6 in. to 14 ft. 6 in.
2*c*	.	10 ft. to 11 ft.
2*b*	.	4 ft. 6 in. to 5 ft. 6 in.
2*a*	.	2 ft. to 3 ft.

All the specimens used in this investigation are preserved in the Department of Geology, University College of Wales, Aberystwyth.

3. Preservation of the Fossils

There are four important considerations as to preservation :—

(1) *The aspect presented.*—Individuals of graptolites with curved polyparies will naturally tend to lie on their sides, and all the present specimens appear to present truly side views. Nevertheless individual thecae, even those next to one another, often differ considerably in shape and particularly in the prominence and form of the apertural beak ; this being quite apart from the regular difference in form and spacing that may occur from the proximal, towards the distal, end. This latter difference is of course inherent in the organism ; but the irregular difference between one theca and the next is probably due to the presentation of slightly different aspects.

(2) *Vertical compression (flattening) due to consolidation of the rock.*—The specimens are all preserved more or less in relief, so that little adjustment, on the whole, need be made on this account to arrive at a true view of the thecal outlines. Nevertheless there are in some thecae signs of two, or several, layers of material replacing the original chitin, the upper (overlying) part of a theca having been apparently pressed down and slightly displaced over the lower.

(3) *Lateral compression due to subsequent pressure on the rock.*—Although the possibility of distortion of this kind does not usually seem to be taken into account in the study of graptolites, it is by no means certain that it is not present in some of these specimens. One might have expected that if any all would have been affected ; but most of the specimens appear quite normal. However, slipping along particular bedding surfaces in the ordinary process of folding may have distorted specimens on those surfaces, leaving others unchanged ; and indeed on one of the specimens there are signs of slickensiding.

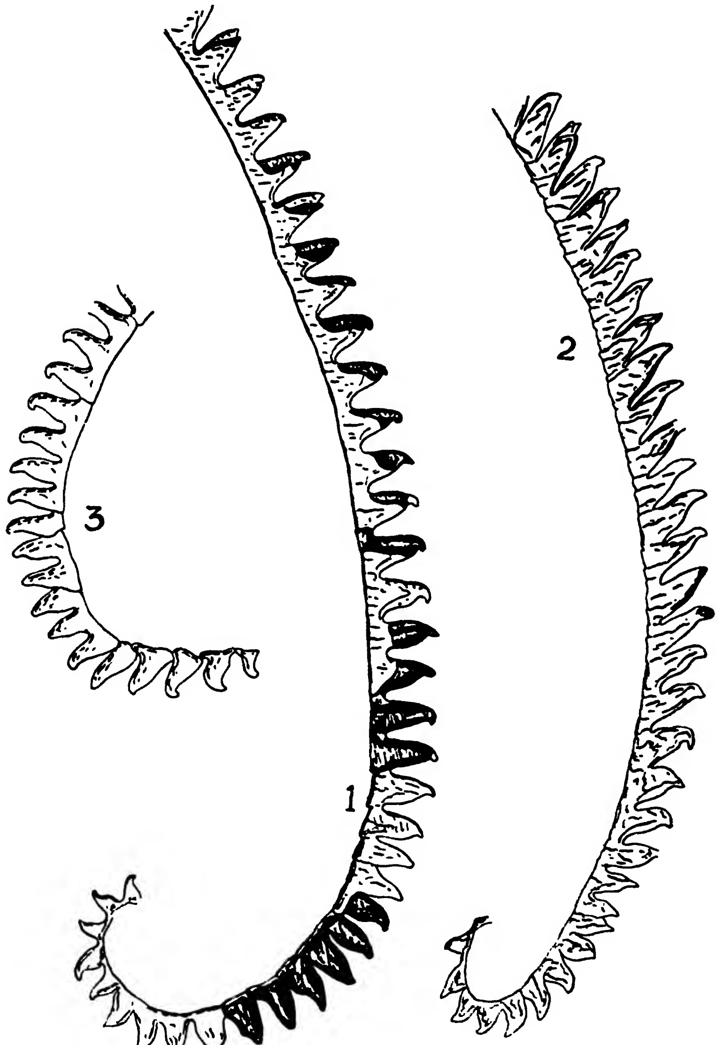
(4) *Type of preservation.*—The original chitinous material has disappeared in most of these specimens, the original skeleton being usually replaced by gypsum. Pyrite forms conspicuously shining internal casts, and also appears to replace the original chitin to some extent. In external impressions in the matrix some of the gypsum is very apt to adhere.

(Since writing this section two papers have appeared in the *Geological Magazine* bearing on the preservation and distortion. of graptolites : Elles, 1944, and Hills and Thomas, 1944.)

4. A Morphological " Continuum "

The specimens, taken as a whole, strongly suggest that there are so many transitional forms between those that conform to named types

that we have here one whole homogeneous group ; especially as all these specimens occur together within a very limited stratigraphical range. There is, however, a considerable difference in appearance between the



TEXT-FIGS. 1–3.—*Monograptus fimbriatus-triangulatus* series. × 5.

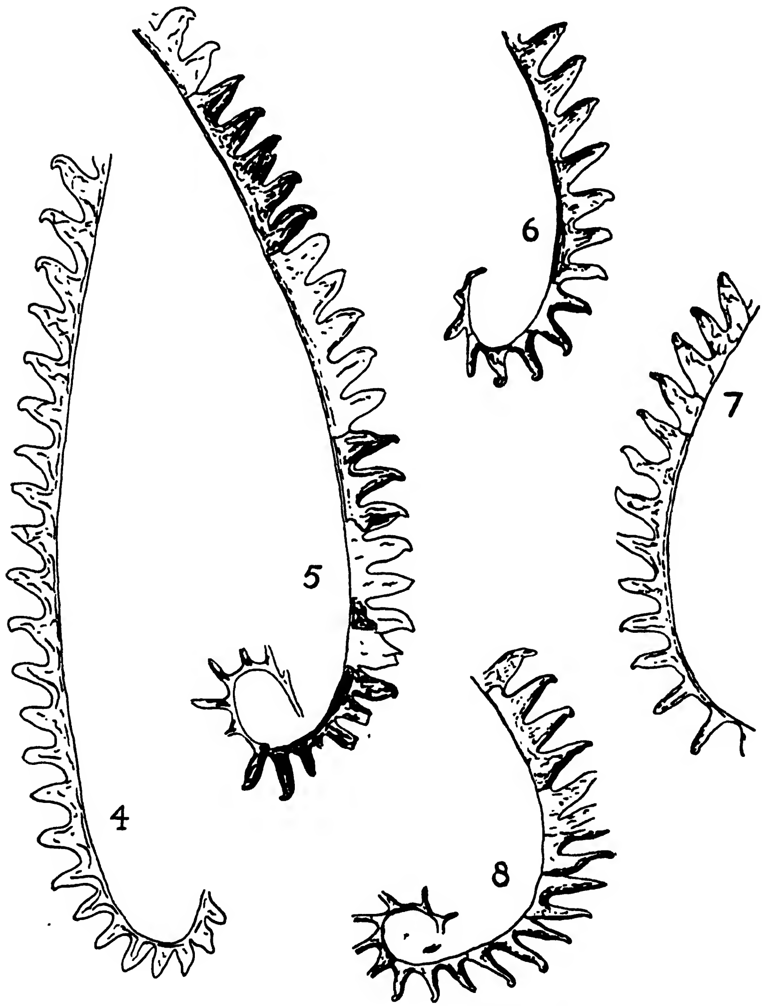
extreme members. A representative selection, showing the range of form, is given in the next section.

We thus seem to have a case of a kind hardly recorded hitherto among the graptolites ; a continuous morphological series, or " continuum ",

covering a wide range of thecal form and spacing. The present investigation makes no attempt at a systematic revision of the forms concerned.

5. Commentary on the Representative Specimens Figured

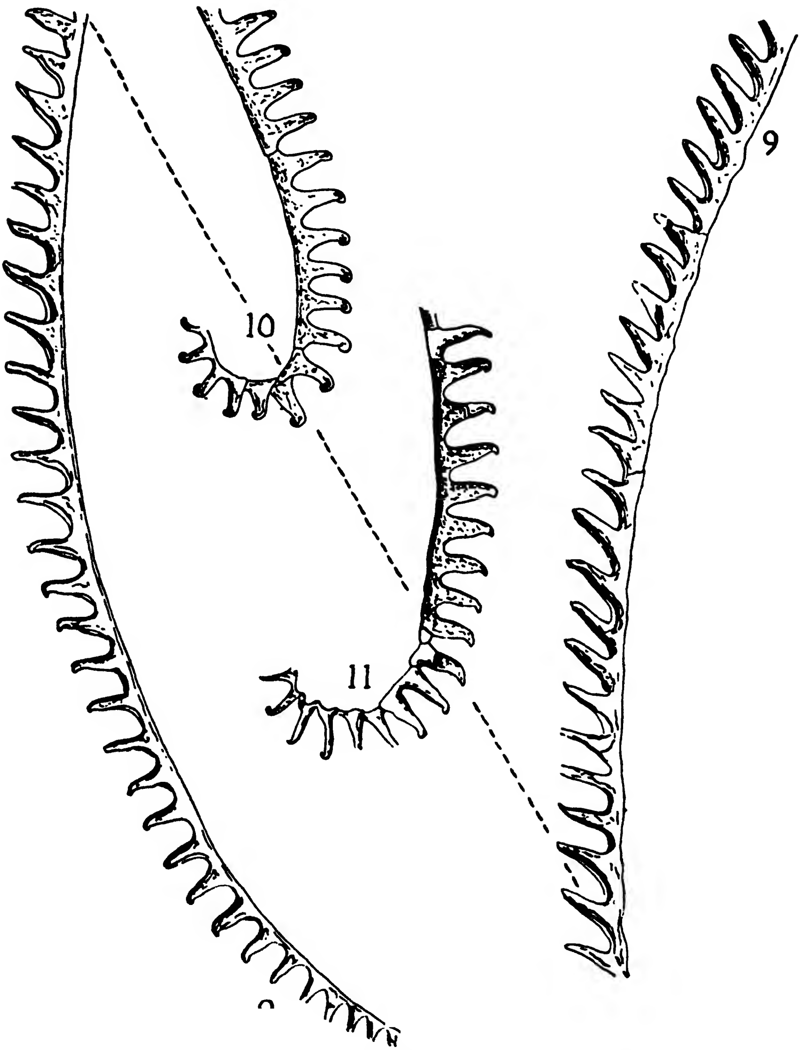
The figures (all × 5) show, in particular, the thecal shape and spacing,



Text-figs. 4–8.—*Monograptus fimbriatus-triangulatus* series. × 5.

and in these respects speak for themselves. The apertures are not visible in any of the specimens, but their positions may usually be inferred from the character of the apertural ends of the thecae. The following brief notes may serve to draw attention to the chief points in the general

morphology of each of the selected specimens, and to record their modes of preservation and horizons. The registered numbers on the specimens, from Nos. 1 to 16 (as given here) in order, are U.C.W. 19557 to 19572.



TEXT-FIGS. 9–11.—*Monograptus fimbriatus-triangulatus* series. × 5.

(1) Some of the original chitin remains; elsewhere the specimen is an impression, with replacing gypsum adhering. The thecae are widely spaced and very broadly triangular, a number of them showing a conspicuous reflexed apertural beak. It is obviously referable to the species

M. fimbriatus. The thecae being all similar in shape, the variety *similis* is suggested; but this is said to have the thecae closely set, whereas in the present specimen they are exceptionally wide apart. It is in this specimen that the chitin shows a striation that may be a slickenside effect; and there are very slight indications of parallel markings on the surrounding matrix. Horizon 2*b*.

(2) The specimen is in low relief, gypsum filling the impression. The thecae are rather narrower and more closely set than in (1), and the beak is developed to about the same extent. The proximal thecae are markedly broader than the others, though this may be due to compression in the plane of the bedding broadening thecae that point in one direction, and narrowing those that point in the direction at right angles. Horizon 2*b*.

(3) An impression. The thecae are a little more widely spaced than in No. 2, and a little narrower in form than in No. 1. A considerable part of the theca is involved in the terminal bend. Horizon 4.

(4) Preserved chiefly as a low relief in gypsum. The thecae are about the same width as in No. 3, but more widely spaced. The beak or lobe is very pronounced in some of the more distal thecae; the proximal thecae are rather wider in proportion than the rest. Horizon 2*a*.

(5) Preserved partly as an impression or in low relief in gypsum, partly in original chitin. The first few thecae, though not fully preserved, are decidedly long, narrow, and well-separated; but the rest are broadly triangular as in specimen No. 1. Horizon 2*d*.

(6) In this little specimen most of the proximal thecae are preserved as internal casts in full relief in pyrite; the rest as external impressions with gypsum adhering. The more distal thecae are rather narrow and regular, while the proximal thecae are a little narrower still and more widely spaced. This specimen thus marks another slight but distinct step away from the *fimbriatus*, towards the *triangulatus*, type of theca. Perhaps the degree of difference between the proximal thecae and the rest would be sufficient to warrant the name *M. raitzhainiensis* rather than *M. fimbriatus* for both this specimen and No. 5. Horizon 2*b*.

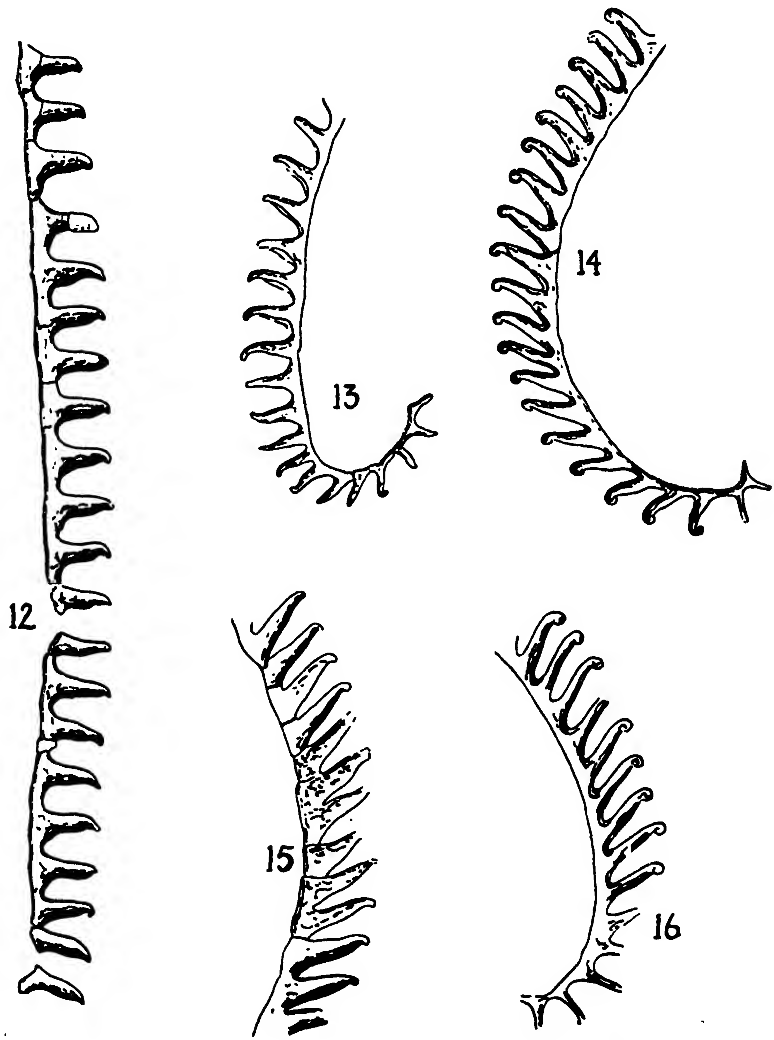
(7) The polypary is preserved in rather low relief, showing the replacing gypsum. The more distal thecae are slightly broader than the thecae of the last specimen, but near the proximal end they are narrow and widely spaced, being decidedly of the *triangulatus* type. This is a typical *M. raitzhainiensis*. Horizon 2*d*.

(8) Chiefly a relief in pyrite. The specimen has the appearance of a *M. raitzhainiensis* that has suffered a certain amount of compression. Horizon 2*c*.

(9) This specimen is almost entirely in the form of an impression. The first twenty-five or so visible thecae (others, more proximal, are not preserved) are of the *triangulatus* type, and these merge distally into fairly typical *fimbriatus* thecae. No doubt *M. triangulatus* would be the appropriate name here; but the specimen is not far removed from *M. raitzhainiensis*. Horizon 4.

(10) An impression. There is no very marked difference between the thecae of the proximal end and those of the rest of the stipe, though the former are again rather narrower and more widely spaced; and these proximal thecae in particular show a well-marked hook. Horizon 4.

(11) The specimen is preserved partly in gypsum, partly as an internal cast in pyrite and partly as an impression. It is rather similar to the last, No. 10; but the proximal thecae are longer and narrower. Each of



TEXT-FIGS. 12–16.—*Monograptus fimbriatus-triangulatus* series. × 5.

these may be named *M. triangulatus*; but there is a little of the *M. raitzhainiensis* character about them. Horizon *2d*.

(12) Preservation is in full relief as a pyrites cast here and there encased in gypsum. This and the remaining four specimens are all undoubtedly

M. triangulatus, though in this specimen the thecae are rather too short and broad to be quite typical of that species. Horizon 4.

(13) The specimen is a typical *triangulatus* with a moderate " linear triangular " type of theca. The curved apertural ends are conspicuous in many thecae ; and some of the more proximal show signs of a definite hook. Horizon *2d*.

(14) An impression, with some gypsum remaining. The thecae are longer than in No. 13, and many are seen to be markedly hooked. The form of the proximal end is particularly well shown. A certain amount of compression (distortion) seems suggested by the general outline. Horizon 4.

(15) The specimen is preserved in pyrite with some of the thecae represented by impressions only. The thecae are about $2\frac{1}{2}$ mm. in length. Horizon 4.

(16) For the most part the specimen is an internal cast in relief. The thecae are long and well hooked, the termination being considerably enrolled. It would undoubtedly come under the varietal name *major*, the extreme form of *M. triangulatus*. Horizon 4.

6. Evidence of Evolution

The continuously graded morphological series being established, it remains to be seen what evidence there may be as to this series being strung out in time, and so forming a lineage.

Owing to the fragmentary nature of most of the specimens it has not been possible to trace statistically the occurrence of the several grades upwards through the rock-sequence ; and after various trials at a more refined discrimination, it was found that the only practicable procedure was to make two large groups.

The specimens collected from each of the five restricted bands were accordingly examined and placed in one of two categories, according as to whether they could be named certainly as *M. triangulatus* or whether they would, rather, come under the names *M. fimbriatus* or *M. raitzhainiensis*. The following table gives the numbers of individuals in each category, with the percentages in brackets, for each of the five bands :—

	fimbriatus and raitzhainiensis.	*triangulatus.*
4 .	40 (77)	12 (23)
2d .	65 (78)	18 (22)
2c .	32 (82)	7 (18)
2b .	34 (94)	2 (6)
2a .	25 (100).	0 (0)

Of course several other graptolite species occur together with those on which attention was concentrated. *Climacograptus törnquisti* is by far the most abundant species at all levels. *M. communis* is also common, and the typical form can be readily distinguished from *M. fimbriatus* ; but some of the specimens, here taken as *M. fimbriatus*, to some extent approach *M. communis* in the shape of the thecae (e.g. Text-fig. 3). These forms occur most commonly at horizon 4, where they are included in the statistics. If they were not so included a greater proportion of

forms at the *triangulatus* end of the series would be shown for that horizon. Also, in considering a lineage, and particularly when considering it statistically, there is always the possibility to be borne in mind that the several grades may not die out as regularly as they come in.

We thus appear to have a definite if limited lineage, proved by the time-occurrence of the two portions of the "chain"; the chain itself, as a series of morphological links, having been demonstrated in the first place.

The following previously published facts and hypotheses should here be recalled.

The stratigraphical distribution of *M. fimbriatus* and *M. triangulatus* as recorded in the *Monograph of British Graptolites* and by Jones (1909) had already shown that the former tends to occur earlier than the latter. The succession of the graptolites, particularly in this part of the British Silurian, suggested to Elles (1922 and later papers) the idea of a general evolutionary morphogenetic trend as regards the thecae, from simple to hooked and from contiguous to isolate; and in her table of suggested phylogenetic lines *M. triangulatus* is shown as derivable from *M. raitzhainiensis.* O. M. B. Bulman (1933, p. 318) also indicates the probable evolution from *M. raitzhainiensis* to *M. triangulatus* and further states, in reference to the former, "there is little doubt that this species must have been preceded by a form of *Monograptus,* as yet unrecognized, in which all the thecae were triangular in shape."

7. Ontogeny and Certain Hypotheses

As with so many graptolites the present forms, particularly those that can be named *M. raitzhainiensis*, show a marked difference between the thecae of the proximal end and those of the rest of the stipe. On the well-known and, at least until recently, highly favoured hypothesis of palingenesis or recapitulation we should expect to find the evolution to be the reverse of what it actually turns out to be, on the incontrovertible stratigraphical evidence; as, where there is a difference, the earliest thecae are generally of more pronouncedly *triangulatus* type than the later ones. The evidence here in fact contradicts the recapitulation hypothesis and supports its reverse, proterogenesis. Elles has already remarked (1922, etc.) on the fact that when *Monograptus* was progressive, as it was at this time, the earliest thecae in an individual are of the most advanced type; whereas in retrogressive stocks, later in the Silurian, the earliest thecae are the ones to retain advanced features. In this latter case, therefore, we may be said to have recapitulation. The bearing of these facts on these hypotheses does not seem to have been commented on; and they cannot be readily explained (as many so-called instances of recapitulation probably can) as a necessity of "growing up", nor as a special adaptation to conditions of embryonic life. We seem to have, among the *Monograpti,* the expression of a tendency for the earliest stages in ontogeny to be the most advanced, whether the stock be evolving "forwards" or "backwards"; but the writer is not aware of such a tendency being in evidence in other groups of fossils.

8. Acknowledgments

In conclusion the writer wishes to express his thanks to Professor H. P. Lewis and Dr. O. M. B. Bulman for the very kind interest they have taken in this investigation, and for their many helpful criticisms and suggestions.

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The Illaenid Pygidium

With special reference to the reflexed border

By J. L. Begg

(PLATE I)

I. Introduction

WITH the removal of certain genera the Illaenidae has become a very homogeneous family. Attempts have been made to group genera into subfamilies, the most important of which was that made by Salter in 1867, but these efforts have not met with general approval. Thus Warburg (1925, pp. 97–100) has given a recent summary of the Illaenid classification and discussed the previous literature, and this author endorses the opinion expressed by Raymond in 1916, " that it is still too early to make any natural classification." Whittard (1938, p. 89) follows Holm and Warburg and meantime would only admit *Illaenus* and *Bumastus* as valid genera and suggests that Salter's genus *Ectillaenus* might be retained for species of Illaenids in which visual organs were either absent or vestigial.

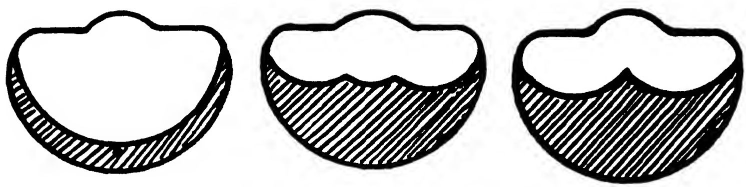
The determination of species of the genus *Illaenus* is often difficult. Illaenids are specialized forms in which most of the characters relied on for specific determination in other trilobites have been lost. For example the trilobation of the dorsal surface is less pronounced, being practically absent in *Bumastus* apart from the thorax ; the glabellar lobes and furrows are absent or only feebly defined, as in *Illaenus revaliensis* Holm. The axial furrows die out towards the front of the cephalon ; there is no pre-glabellar furrow and the real length of the glabella is not recognized ; there is rarely a marked occipital furrow. The Illaenid thorax is composed of eight, nine, or ten segments, in which the axial rings and pleurae are of a simple nature, the pleurae lacking pleural furrows and ridges. The Illaenid pygidium in outline is subsemicircular to subtriangular ; it is usually broader than long, and the articulating facet at the antero-lateral angles is a marked feature. The axis of the pygidium varies greatly and this feature will be discussed later.

My warm thanks are due to Professor Trueman and Dr. C. J. Stubblefield for very considerable help with the text of this paper, as also for many valuable suggestions and criticisms which are gratefully acknowledged and appreciated.

II. The Reflexed Border of the Illaenid Pygidium

What has been stated in the foregoing may suffice to demonstrate the difficulties with which authors may be confronted in specific determination. A feature in the reflexed border of the Illaenid pygidium, however, may prove of considerable value for this purpose. Unfortunately, unless the under side of the doublure is found exposed, which rarely occurs, it is necessary to chip away the matrix lying between the dorsal surface and the doublure. This process must be carried out with care, especially as the median portion of the anterior margin of the doublure is approached. When this has been successfully accomplished it will be found that the

doublure, or rather its impression, presents one of three different aspects: (1) the anterior margin may consist of a simple concave curve approximately concentric with the lateral and posterior margins of the pygidium and stretching from the antero-lateral angle on one side to that on the other side of the pygidium; (2) it may consist of three curves separated from each other by two points protruding forward; or (3) it may be composed of two curves separated from each other by a single point or cusp.



a b c

TEXT-FIG. 1.—Line drawings of the reflexed border of Illaenid pygidia. The reflexed border of (*a*) is narrow and of fairly uniform width; of (*b*) and (*c*) the border is of much greater width in the middle region, the anterior border in (*b*) being composed of three curves, and in (*c*) of two curves with an intervening point.

By chipping away the posterior end of several pygidia I have sometimes succeeded in revealing the nature of the anterior margin of the doublure, and in certain instances this was necessary before an accurate specific determination could be made.

III. ORIGIN OF THE VARIATION IN THE ANTERIOR MARGIN OF THE REFLEXED BORDER

Holm (1866, p. 29) described the generic features of the Illaenid reflexed pygidial border, which I translate as follows: "The doublure varies considerably in its form. It is either uniformly broad and then usually rather narrow, or it increases in width posteriorly. In the last instance it forms towards the front at the mid-line a wide scolloping as in *I. esmarki* Schlot., or it projects forward forming a point of which the sides are strongly or weakly curved. . . ." In his specific description of *I. esmarki* (p. 51) it is stated: "The doublure at the posterior increases strongly in width; on the anterior margin at the mid-line a median curve is formed, thereby producing on the margin three bays and two prominent obtuse angles," and in *I. linnarssoni* forma *avus* Holm (p. 150) it is stated: "The doublure is very broad and arched. Its front margin has medianly a broad bay delimited by a pair of blunt points." Warburg (1925, p. 125) raised *I. linnarssoni* forma *avus* Holm to specific rank as *I. avus* Holm, and in the description of the doublure stated (p. 127) "the anterior margin is arched backwards in the middle and the pair of points at the side of the arch are very distinct". I have quoted these authors at some considerable length to show that they refer to the median curve on the anterior margin of the doublure as a "scalloping" or an "arching backwards", and

that no reference is made to the nature of the lateral curves on the margin. It is to be noted that the scalloping and arching backward is not of a simple concave curve stretching from one side of the pygidium to the other. The two outer curves are not separated parts of the same arc, and their curvature is such that if they were continued inward they would meet at the median line forming a point projecting forward, the sides of which would be curved to a greater or less extent.

In the Illaenidae the determination of species may often demand knowledge of the reflexed border of the pygidium just as in the Asaphidae it is necessary to ascertain what type of hypostome is present to be certain as to which group and subfamily the species should be referred. In the Girvan species *Illaenus fluvialis* Reed of Ashgillian age, and *I. roemeri* Volborth of the East Baltic Provinces and Sweden, there is such a close resemblance in the dorsal aspect of the pygidia of the two species that they could reasonably be considered, if not conspecific, at least varieties of the same species. The former, however, possesses the broad reflexed border in the pygidium with the three-curved anterior margin, while the border of the latter has a simple concave curve. *Illaenus drummuckensis*, a new species from Girvan, has been described by Dr. Reed, and at the moment of writing is in press. The pygidium of this example very closely resembles that of *I. wimani* Warburg from the Upper Leptaena Limestone of Dalarne, but again the anterior margin of the reflexed border of the Girvan form possesses three curves while the Swedish species has the simple curved form.

Note on the Illaenid Axis

There is considerable variation in the axis of the Illaenid pygidium; it may be long or short, broad or narrow, arched or only so anteriorly, or it may have little or no independent convexity as in *Illaenus grandis* Billings. The axial furrows may be well defined or they may die out posteriorly so that no post-axial furrow marks off a post-axial area. For the present purpose these axial features will be arranged in convenient groupings A, B, C, and D, showing the stages attained in the disappearance of the axis, but the groups are not intended to represent natural groups.

Group A.—Axis complete, broad or narrow, with a well-rounded posterior end. In this group the following species are included. *I. augusticollis* Billings and *I. conradi* Billings from the Black River Group, both species have a narrow pygidial axis; *I. sphaericus* Holm, *I. avus* (Holm), and *I. proles* Holm, the two former are from Etage C 2, C 3 (Ordovician), the latter species from Etage H (Silurian) of the East Baltic Provinces; all possess a broad well-formed axis. *I. darlecarlicus* Warburg, from the upper Leptaena Limestone of Kallholm, Sweden, has a short but well-formed axis. A small example from the Balclatchie Group of Girvan tentatively referred to *I. latus* McCoy might also be included in this group.

Group B.—Axis complete, convex anteriorly, less so posteriorly, usually subtriangular in form, sides tapering to a blunt or narrow pointed end, in which is included *I. sulcifrons* Holm with a broad axis; *I. schmidti* Nieszkowski and *I. intermedius* Holm with a moderately broad axis; *I. dalmani* (Volborth), *I. revaliensis* Holm, *I. tauricornis* Kutorga and

I. atavus Eichwald have a narrow axis, and they are all from Etage C 1 of the East Baltic Provinces.

Group C.—Axis incomplete, broad or narrow, and indicated mainly by a median arch on the anterior border of the pygidium, on each side of which there is a marginal indentation and immediately behind it a shallow depression, short or continued a slight distance backward, posteriorly there is no independent convexity. In this group are included the following species which are characteristic of Upper Ordovician and Silurian horizons, *I. roemeri* (Volborth) from Etage F 1, of the East Baltic Provinces, *I. longicapitatus* Reed of Ashgillian age, Girvan, *I. fluvialis* Reed same horizon and locality, *I. thomsoni* Salter and *I. aemulus* Salter in the Saugh Hill Group, Girvan District, and *I. grandis* Billings Mid-Silurian of Anticosti Island.

Group D.—Axis obsolete, a slight marginal furrow may be present on the pygidium as is the case in *Bumastus*. This type is represented by *Bumastus maccullumi* Salter and *B. barriensis* Murchison, both species are present in the Saugh Hill Group (Mid-Valentian) of the Girvan District. The few species given are typical of the different groups, but many others might be added.

From the variations in the axis of the Illaenid species referred to above it is feasible to conclude that there is a series of stages towards obsolescence. In Group A the axis is well defined, in Group B it tapers posteriorly where it is feebly defined, in Group C it is anteriorly inconspicuous and posteriorly dies out, in Group D it is obsolete. It is assumed that the narrow reflexed border, in which the anterior margin runs in a simple curve from one side of the pygidium to the other, is the original and earlier type, and that the forms with an increased width in which the anterior margin has suffered "scalloping" or been "arched backward" are later and have been developed from the simple type. It is considered that the simple type is normal and resembles more closely the general structure of the reflexed border of the trilobite pygidium. This view is supported by the terraced lamellar lines. They do not appear to have been affected by the curvatures of the anterior margin, but persist in all three types to run concentric with and parallel to the border of the pygidium. It is not contended that the terraced lines are growth lines, they may be a source of strength and reinforcement of the doublure comparable with the "lists" on the roll of *Tretaspis*. If the assumption that the simple curved anterior margin is earlier, is correct, then a forward progression of the doublure would not be arrested until it came up against the round posterior end of the axis, resulting in a curved indentation of the anterior margin. On either side of the median curve the doublure would be free to make a further slight advance.

The retreat of the axis from the posterior end would again permit a free progression forward of the doublure medianly, and the lateral curves if continued inwardly would meet at a point on the median line protruding forward.

In seeking evidence to substantiate the view here advanced a difficulty at once presents itself. Our knowledge of the reflexed border of the Illaenid pygidium is limited to comparatively few species in the family. That something of this kind did occur, however, is supported in quite

a few instances, some of which are indicated by the figures in the plate illustrating this paper. Seven of these are reproduced by photography from Holm's plates 1–12. In *Illaenus avus* (Holm), our Plate I, figures 5 and 6, it is fairly evident that the advancing doublure in figure 6 has been arrested by the well-rounded posterior end of the axis. In figure 5 the axis has somewhat retreated and the doublure is seen to be advancing again inside the median anterior curve of the anterior margin. Figures 1 and 2 are referred by Holm to *I. esmarki* and *I. revaliensis* respectively; they are very similar and appear closely allied species. In figure 1 the median anterior curve is present with the axis in process of retreating, in figure 2 the median curve has disappeared, and in the position it occupied further advance has been made by the doublure, and a median point is in process of formation. Figure 8 is a small example in my collection which has been referred with doubt to *Illaenus latus* McCoy [1]; in it the median curve of the anterior margin is seen to coincide with the posterior end of the pygidium. In figure 7, *I. juvensis*, a median point separates two anterior curves, and the axis has all but disappeared.

Objection may be raised to the views which have been postulated regarding the forward progression of the doublure, the retreat of the axis in the Illaenid pygidium, and the effects that these may have had upon the anterior margin of the doublure. It may be questioned why, in those members of the Illaenidae in which the pygidial axis has retreated, the anterior margin of the doublure retains what has been considered its original form, narrow and with a simple concave curve. *Illaenus roemeri* Volborth is an example of this kind (Holm, 1886, pl. xii, figs. 12–15). In *I. masckei* Holm, however, a very broad flat band surrounds the pygidium laterally and posteriorly and occupies more than one-half of the whole pygidial area. The inner central part of the pygidium is elevated, rising suddenly with a "roll" from the inner margin of the outer broad band. It appears evident that in its progression forward in this case the doublure has been arrested exactly where the outer band comes into contact with the inner elevated area of the pygidium, see Pl. I, figs. 3 and 4.

IV. The Terraced Lamellar Lines of the Illaenid Pygidial Doublure

Terraced lines occur on both upper and under sides of the pygidial doublure (Holm, 1886, p. 29). They show considerable variation. These lines are generally concentric, running parallel with the border of the pygidium. In *I. roemeri* Volborth the doublure is narrow, the terraced lines are regular and at equal distances apart. *I. jevensis* Holm (see Pl. I, fig. 7) has terraced lines which are ouite irregular. Variation of this nature may occur within a species. The terraced lines in *I. fluvialis* Reed are spaced at irregular intervals and appear to bifurcate or die out, but in one example from South Threave in the Drummuck Group of Girvan I find that the terraced lines are well defined and at regular distances apart. In *I. revaliensis* Holm (see Pl. I, fig. 2, here, which is

[1] Since the foregoing was written I have found at Balclatchie a pygidium of *Illaenus latus* McCoy. The fascia was exposed revealing that the anterior margin of the doublure possessed the three-curved form, the median curve abutting and coinciding with the posterior end of the pygidial axis.

Holm's figure, pl. ii, fig. 8*a*) the concentric curvature of the terraced lamellar lines is interrupted at the median line where they are deflected backwards in the form of a short triangular point. This may be due to the presence of a median downward bend of the doublure at the mid line of the pygidium. In *I. superstes* Reed (1944, p. 60, pl. ii, figs. 5, 6) the terraced lamellar lines are straight, equidistant, cutting obliquely across the pygidium at the postero-lateral angles, meeting the mid line at an angle of about 50 degrees.

V. Conclusion

It is suggested that a knowledge of the doublure of the Illaenid pygidium in certain instances is essential for specific determination. It is suggested that the differences in the form of the anterior margin of the doublure may be related to variations in the form and strength of the axis of the pygidium. This hypothesis cannot be established, however, until there is more knowledge of the form of the doublure in a wide range of other species.

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EXPLANATION OF PLATE

[The figures 1–7 are reproduced from the figures in Holm (1886, pls. 1–12). The plate and figure numbers are given, and the pygidial width which Holm's figures measure.]

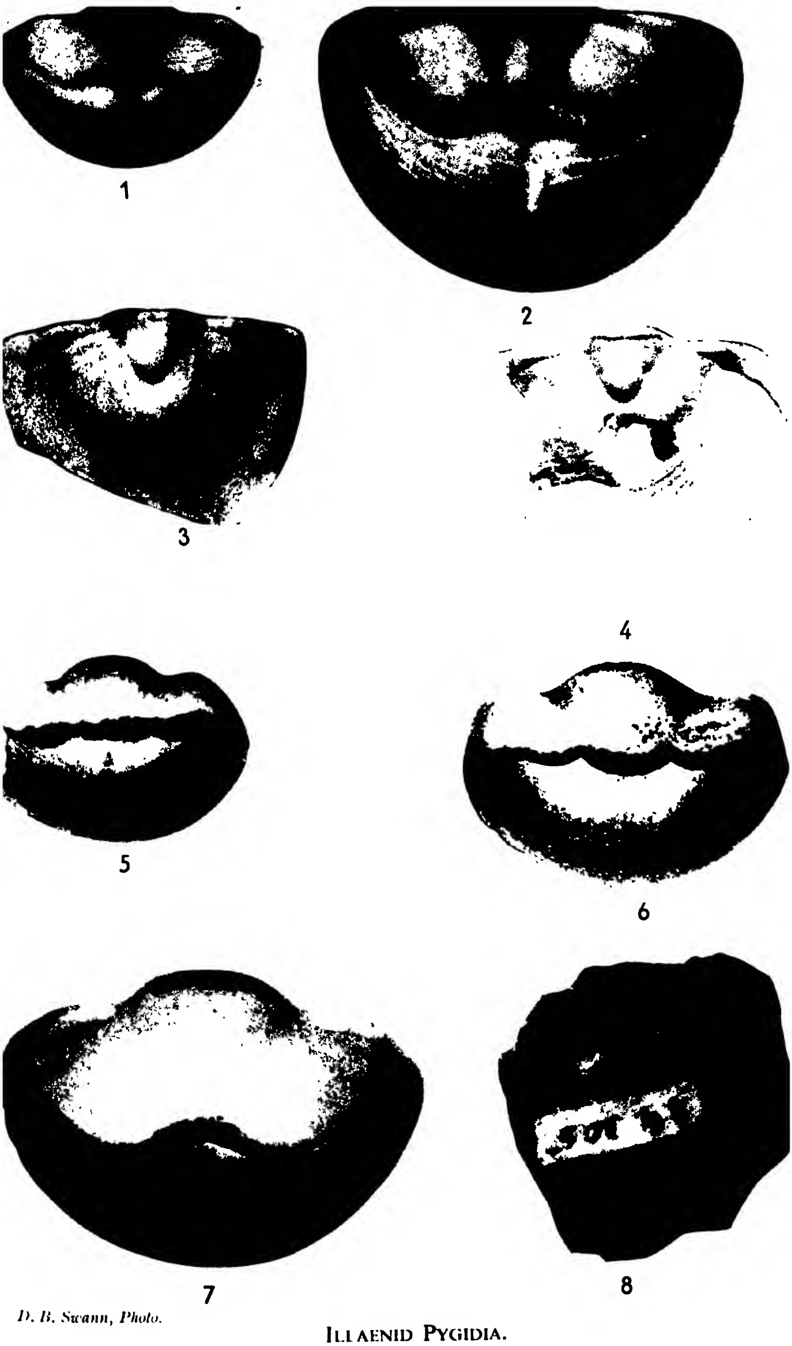
Fig. 1.—*Illaenus esmarkii* Holm, a pygidium, the anterior margin of the doublure is composed of three curves, the shorter median curve is separated from the two lateral curves by two intervening points (Holm, 1886, pl. i, fig. 6, width 35 mm.)—Wolchow, Iswos.

Fig. 2.—*Illaenus revaliensis* Holm. The anterior margin of the pygidial doublure has two curves with a broad, bluntly-rounded, area intervening (pl. ii, fig. 8*a*, width 51 mm.)—Reval.

Fig. 3.—*Illaenus masckei*, the pygidium is surrounded laterally and posteriorly by a broad, flat band, enclosing an inner elevated area which rises with a " roll " from the inner edge of the band (pl. xii, fig. 5, width 51 mm.)—Pallokühl, Island of Dagö.

Fig. 4.—*Illaenus masckei*, an incomplete pygidium, the larger portion of the doublure is preserved with its anterior margin abutting against the inner elevated central area of the pygidium ; the terraced-lines are concentric with the pygidial margin and approximately equidistant apart (pl. xii, fig. 4, width 35 mm.)—Ehstland, Kirna.

Fig. 5.—*Illaenus avus* (Holm), an imperfect pygidium, in the median curve of the anterior margin a further forward progression of the doublure is visible (Holm, pl. x, fig. 13, width 30 mm.)—Kegal.



D. B. Swann, Photo.

ILLAENID PYGIDIA.

FIG. 6.—*Illaenus avus* (Holm), a pygidium showing the three curved scalloped anterior margin of the doublure (Holm, pl. x, fig. 10*d*, width 40 mm.). Erras.

FIG. 7.—*Illaenus jevensis* Holm, a complete pygidium, the doublure is almost entirely exposed, the terraced-lines are more or less irregular (Holm, pl. x, fig. 5*a*, width 37 mm.)—St. Mathias.

FIG. 8.—? *Illaenus latus* McCoy, pygidium of a young individual, the doublure anterior margin has the scalloped form, the curve on the right-hand side is best seen, the median and curve to the left are somewhat obscured by matrix, width of pygidium 5 mm. Locality: Balclatchie, near Girvan.

Tyrieocrinus (gen. nov.) and *Scotiacrinus* (gen. nov.) and Seven New Species of Inadunate Crinoids from the Carboniferous Limestones of Scotland and Yorkshire.

By JAMES WRIGHT

(PLATES II–IV)

THE majority of the Scottish specimens described in this paper consist of cups only, and have been in my collection for a long time. In earlier days they would probably have been assigned to genera like *Poteriocrinites* and *Pachylocrinus*, but in recent years great additions have been made to our knowledge of Carboniferous inadunate crinoids by American workers such as Kirk, Moore, Laudon, Strimple, and others. New genera and species have been created, many of them based on all the characters of complete crowns. Obviously, when dealing with cups alone, it is not always easy to trace exact relationship to such perfect examples of crinoid life. It seems evident, however, that the cups here dealt with differ in certain ways from forms so far described, and an attempt is now made to give them specific standing. Four new species are ascribed to known genera, three, including two new species, to the new genus *Scotiacrinus*, and one to a new Cromyocrinid genus for which the name *Tyrieocrinus* is proposed. A revision is also given of the species previously described as *Erisocrinus scoticus* (Wright, 1942, pp. 275–6) and now referred with reservations to *Apographiocrinus* Moore & Plummer. I wish here to thank Dr. A. C. Stephen, of the Royal Scottish Museum, for the loan of a specimen belonging to that institution, now named *Scotiacrinus yoredalensis*, and the authorities of the Museum for permission to describe and figure it.

CROMYOCRINIDAE Jaekel (1918)

Tyrieocrinus gen. nov.

A Cromyocrinid with globose cup, much wider than high ; IBB circlet slightly convex, occasionally almost flat, just visible in side view and rather large in proportion to BB ; BB very tumid ; RR circlet greatly constricted ; R facets sloping inward to cup with strong articulating cross ridge ; plates rather thin, smooth, sutures flush ; anal area occupied by one large plate resting on post. B and extending slightly beyond line of RR ; column socket shallow ; arms unknown.

Genotype.—*Tyrieocrinus laxus* sp. nov. (figured as "unknown species" in Wright, 1939–1940, pl. xii, figs. 21–2).

Tyrieocrinus laxus sp. nov.

Pl. III, figs. 1, 6–15, 17, 19, 21, 23, Text-figs. 1–4.

Holotype.—J. W. Coll., 2477, from No. 1 Bed, Invertiel, near Kirkcaldy, Fife (Pl. III, figs. 8, 10, 11, 13–15, 19).

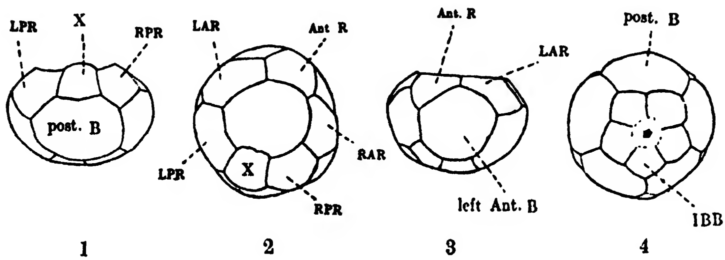
Paratypes.—J. W. Coll., 2478, from No. 1 Bed, Invertiel ; 2374*a* and *b*, from No. 1 Bed, Invertiel (Pl. III, figs. 1 and 6) ; 1643, from Seafield Tower Limestone, Seafield, near Kirkcaldy, Fife (Pl. III, fig. 9).

Other Localities.—Duloch, Charlestown, Roscobie, Fife ; Carlops, Peeblesshire.

Horizon.—Lower Limestone Group (Mississippian).

Dimensions of Holotype.—Height of cup, 14 mm.; width over all below constriction of radial circlet, 21 mm.; average length of IBB from lumen, 7 mm.; height of post. B, 11 mm.; height of right ant. B, 9·3 mm.; average height of RR, 8 mm.; width of RR, RPR, 5·3 mm., LPR, 6 mm., LAR, 7 mm., ant.R., 5·8 mm., RAR, 6 mm.

Remarks.—Infra-basal circlets, probably belonging to the present species, have been known to me for many years. They were always found detached, with no trace of the cup to which they belonged, and although it was suspected that they represented a genus like *Cromyocrinus* it was difficult to assign them with confidence to this or any other genus. In the shales overlying the Seafield Tower Limestone, however, on the shore at Seafield, near Kirkcaldy, Fife, I recently discovered a specimen in which the infra-basal circlet is associated with other plates of the cup (Pl. III, fig. 9). This specimen gave a clue to the identity of the circlets



TEXT-FIGS. 1–4.—*Tyrieocrinus laxus* gen. et sp. nov. Posterior, ventral, left lateral, and basal views of the holotype from No. 1 Bed, Invertiel, nat. size.

and induced me to make a search in my collection for any other specimens that might throw further light on the subject. Among specimens from Invertiel, laid aside for cleaning and future examination, two cups were found, both extremely dirty and obscured by an encrustation of hard calcareous shale. These two cups have now been cleaned. One turns out to be specially well preserved and is taken as holotype of the present species (Pl. III, figs. 8, 10, 11, 13–15, 19, Text-figs. 1–4). From the general shape of the holotype it was at first thought to be a species of *Cromyocrinus*, but as cleaning proceeded it was found that the anal area is occupied by one plate only instead of the primitive three-plate plan of *Cromyocrinus*. The second specimen, although much crushed, has the radial circlet intact, and also shows the single plate structure in the anal region. In the photograph of the Seafield Tower specimen (Pl. III, fig. 9) the infra-basal circlet is at the bottom where it overlies one of the basals. Just above, in the centre, is seen another basal, and to the left of these basals is part of a third basal which is broken away to the left hand side. On the right of photograph, opposite the basal in centre, are two radials with the inner surface upwards. Another radial is also seen projecting from below the top left corner of centre basal. This radial has the inner surface upwards and partly underneath it, on the top left of photograph, is another

radial also with its inner surface upwards. On the top right of photograph is a detached pentagonal plate which is taken to be the anal plate. It is somewhat rounded at the top in a similar way to that of the anal plate in the other two specimens.

These three specimens clearly show that we are here dealing with a distinct form. The new genus *Tyrieocrinus* is therefore proposed to include the present species and other Cromyocrinids having a bowl-shaped cup like *Cromyocrinus*, but one plate only in the anal region. In the species of *Cromyocrinus* so far described the primitive three-plate anal structure is the accepted one for the genus. In *Ulocrinus*, also assigned to the Cromyocrinidae, the structure of the anal area varies in the different species (*U. kansasensis* Miller & Gurley, *U. sangamonensis* Meek & Worthen, *U. buttsi* Miller & Gurley, etc.), but is always of an advanced type, and in *U. buttsi* reaches a stage in which the RA is quite detached from right posterior basal. In *U. bockschii* (Geinitz) the great majority of specimens have a large RA surmounted by one or two small plates (X and RX). The shape of the cup is sub-globular to elongate. At one end of this species group, however, is a small series exhibiting a more primitive type of anal area, and these also vary a good deal in shape. At the other end is a still smaller series which show a much more advanced anal area than the normal for the species. Here the RA is detached from right posterior basal, and this type, while varying among themselves, simulates in some degree the anal structure of *U. buttsi*. One of these variations already figured (Wright, 1939–1940, p. 29, text-fig. 24) has some resemblance to the present species, but the shape and height to width ratio—H 14, W 15, against H 14, W 21 of the present form—and the higher IBB circlet are quite different and typical of *Ulocrinus bockschii*, not of *Cromyocrinus*.

The holotype, with its constricted radial circlet, has in shape a considerable resemblance to *Cromyocrinus simplex* Trautschold, but, apart from the distinct anal area, differs in the thinner nature of the plates, the more flush sutures, and by the proportionally larger infra-basal circlet and more tumid basals. For comparison a basal view of the holotype is given alongside one of *C. simplex* from Russia (Pl. III, figs. 19, 20). Both specimens are nearly the same size. An interesting point about the detached infra-basal circlets mentioned above is the variable nature of the column scar. In some specimens it is very shallow and indicated only by a crenulated ring which rises a little above the level of the infra-basals with no distinct pit or depression (Pl. III, figs. 7 and 17). In other specimens the central area is more depressed, and in a few others a pronounced pit is noticeable (Pl. III, figs. 1 and 6). In the holotype the central pit is quite distinct, but in the Seafield paratype the central area is little depressed (Pl. III, fig. 9). In all specimens the lumen is very small and pentalobate. In the holotype and in the Seafield specimen the radial facets can be examined, but they are best preserved on detached radials, especially on those obtained in shale washings from Carlops (Pl. III, figs. 21 and 23). The column is not known for any length. On one of the infra-basal circlets from Roscobie seven of the proximal columnals are adherent. They are of uniform thickness, slightly rounded, and with strongly crenulated edges.

SCYTALOCRINIDAE Moore & Laudon (1943)

Aphelecrinus Kirk (1944)

Aphelecrinus dilatatus sp. nov.

Plate II, figs. 5–15

Cup elongate, conical, or bell-shaped ; anal area normal, occupied by three plates, RA, X, and RX ; X and RX extend for greater part of their length beyond R circlet of cup ; IBB circlet of moderate height, less than half as high as BB ; BB tumid ; RR crescentric, widely splayed out, curving inwards to sutures with considerable gap betwen facets ; R facets directed outwards ; plates smooth.

Material.—Two cups from No. 1 Bed, Invertiel, and one from Roscobie.

Holotype.—J. W. Coll., 2464, from Invertiel (Pl. II, figs. 8, 12–14).

Paratypes.—J. W. Coll., 2465, from Invertiel (Pl. II, figs. 5, 7, and 10) ; 2470, from Roscobie (Pl. II, figs. 6, 9, 11, and 15).

Horizon.—Lower Limestone Group (Mississippian).

Dimensions of Cups.—Holotype ; height over all, 6 mm. ; width across cup from left to right ant. RR, 9 mm. ; width, anterior to posterior to outer edges of X and RX, 10 mm.

Paratype, 2470 ; height over all, 10 mm. ; greatest width from left post. R to right post. R, 18 mm. ; width from left ant. R. to right ant. R, 16 mm. ; width from ant. R. to outer edges of X and RX, 19 mm.

Remarks.—The nearest described genus to which the present species can be referred appears to be *Aphelecrinus* Kirk (1944, pp. 190–201, pl. 1) or perhaps *Cosmetocrinus* Kirk (1941, pp. 86–8, pl. 17). None of the species figured by Kirk have cups in which the radials are so much splayed out, and it is possible we are here dealing with an undescribed genus. Without any knowledge of the arm structure in our specimens, however, it seems better to assign them to known genera like the two mentioned rather than create a new name. On the whole our cups appear to have more resemblance to *Aphelecrinus* than to *Cosmetocrinus*, and they are here placed provisionally under the former genus. Two of the species figured by Kirk, viz. *A. lyoni* and *A. limatus* seem to have cups with somewhat spreading radials, curving inwards with a gap between the R facets. These features, however, are not so pronounced as in the present species where the extraordinary spread of the radials at once attracts the eye. A cup from the Permian of Timor figured by Wanner (1921, pl. viii, fig. 5) as *Poteriocrinus malaianus* has some resemblance to the present form, but has different radial facets. Although small the holotype is particularly well preserved, and shows all the main characters of the species as noted above (Pl. II, figs. 8, 12–14). The two paratypes are larger. No. 2465, from Invertiel, is slightly crushed at the anterior side, and allowance must be made for this when looking at the top view (Pl. II, fig. 5), where the character of the R facets and their outward flare are well shown. The Roscobie paratype (2470) is attached to a hard limestone matrix so that the top cannot be seen, but the outward spread of the radials, side and basal characters of the cup are well displayed (Pl. II, figs. 6, 9, 11, 15).

Aphelecrinus parvus sp. nov.

Plate III, figs. 2–5

A small species; cup much wider than high; RR flaring, distinct gap between facets; IBB low; BB about one-third higher than IBB; RR nearly twice the height of BB with tendency for LAR, Ant. R and RAR to meet IBB; plates smooth.

Holotype.—J. W. Coll., 1640, from No. 1 Bed, Invertiel (Pl. III, figs. 2–5).

Dimensions of Holotype.—Height of cup, 3 mm.; greatest width from left ant. R to right ant. R, 5·9 mm.; width from post. to ant., 5 mm.

Horizon.—Lower Limestone Group (Mississippian).

Remarks.—Only one specimen of this species has so far been found. Its relationship to *A. dilatatus* is based more on the splayed-out nature of the radials than on the shape of the cup which is low by comparison. Then in this species it is interesting to note the tendency for one or more of the radials to meet the infra-basals, a feature which is also noticeable in certain species of *Hydreionocrinus* and *Anemetocrinus*. In the anal area of the holotype X and RX are missing. The structure here seems similar to that of *A. dilatatus* with X and RX projecting considerably beyond the radial circlet.

Aphelecrinus roscobiensis sp. nov.

Plate III, figs. 16, 18, 22

Cup of moderate size, bell-shaped, wider than high; IBB moderately high forming an appreciable part of calyx wall; BB about twice as high, spreading out in their upper parts; RR flaring, curving inwards to sutures, with small gap between; R facets directed upwards; plates smooth, sutures flush.

Holotype.—J. W. Coll., 2473, from Roscobie.

Dimensions of Holotype.—Height of cup over all, 17 mm.; width, laterally, 28·5 mm.; width, post. to ant., 28·6 mm.

Horizon.—Lower Limestone Group (Mississippian).

Remarks.—This species is founded on one cup. It is not to be confused with the cups of *Pachylocrinus dunlopi* Wright (1939–1940, p. 20, pl. vii, figs. 1, 9) now assigned to *Aphelecrinus* by Kirk (1944, p. 193), or of *Pachylocrinus tielensis* Wright (1939–1940, p. 19, pl. v, fig. 10; pl. vii, figs. 2–4). Although bearing some resemblance to the cups of these species the present form differs in the smoother character of the cup generally, the sutures being quite flush, and the strong outward flare of the radials. The curving inwards of the radials at the sutures and the gap between them are also more prominent features than in the species mentioned.

HYDREIONOCRINIDAE Jaekel (1918)

Hydreionocrinus de Koninck

Hydreionocrinus artus sp. nov.

Plate II, figs. 16–24

Cup low, saucer shaped; IBB just visible from side; left ant. B and left and right post. BB very small; all RR excepting RPR and occasionally LPR joining up and having a wide junction with IBB; anal area variable; ornamentation coarsely granular or vermiculate.

Holotype.—J. W. Coll., 2357, from Seafield Tower Limestone, Seafield, near Kirkcaldy, Fife (Pl. II, figs. 16–19).

Paratypes.—J. W. Coll., 2474, from No. 2 Bed, Invertiel (Pl. II, figs. 20, 23, 24) ; 691, from Roscobie, Fife (Pl. II, figs. 21, 22).

Dimensions of Holotype.—Height of cup, 6·3 mm. ; greatest width, laterally, 18·6 mm. ; width from post. to ant., 18·6 mm.

Dimensions of Paratype 2474.—Height of cup, 6·4 mm. ; greatest width, laterally, 17·9 mm. ; width from post. to ant., 17·6 mm.

Dimensions of Paratype 691.—Height of cup, 8 mm. ; greatest width, laterally, 27·5 mm. ; width from post. to ant., 23 mm.

Remarks.—This species is represented by the three cups mentioned above. They have a superficial resemblance to cups of other species of *Hydreionocrinus*, but are distinguished by the less tumid character of the plates, and they are less grooved along the sutures. They are thus smoother in outline. The cups are also more shallow than typical species like *H. woodianus*, etc. Their most distinctive character, however, is the small size of the anterior and left anterior basals. This is particularly noticeable in the holotype (Pl. II, fig. 16), but is not quite so pronounced in paratype 2474, although the basals here are also quite small (Pl. II, fig. 20). In the other paratype, 691, the two anterior basals are small, but the left anterior is more normal in size (Pl. II, fig. 21). The result here is that the left posterior radial does not meet the infra-basal circlet as in the other two specimens. In the holotype and paratypes, however, the meeting of radials with infra-basals is a pronounced feature, and, with the exception noted, affects all the radials except right posterior radial. The junction between these plates is broad. The anal area in the three cups is extremely variable, no two of which are alike (Pl. II, figs. 18, 22, 23). In the holotype the posterior basal is surmounted by three plates which we may regard as the RA, X, and RX. Ra is very small, and has become quite detached from the right post. basal (Pl. II, fig. 18). Paratype 2474 shows a more normal type of structure, but here the RA, while having a wide junction with right post. basal, also joins the right post. infra-basal (Pl. II, fig. 23). In the Roscobie paratype (691) RA, while still joining the right post. basal, has a wide junction with left and right post. radials, and is surmounted by two plates which for the greater part of their length are outside the cup limits (Pl. II, fig. 22). For comparison with these cups a photograph of a Roscobie specimen of *Hydreionocrinus woodianus* de Kon. is given on Pl. II, figs. 1–4. This specimen shows the usual characters of the cups in that species. No trace of arm structure has been found so that the reference of the present species to *Hydreionocrinus* is only provisional.

PACHYLOCRINIDAE Kirk (1942)

Scotiacrinus gen. nov.

A Pachylocrinid with bowl-shaped cup ; IBB small and sunk in deep cavity, not visible from side ; BB very tumid ; RR rounded, not flaring ; R facets full width and slight gap between RR ; plates of cup ridged or corrugated where they join one another, and sutures much sunken below level of plates ; anal area normally of three plates, RA, X, and RX ; primibrachs one ; arms uniserial, rather long, and branching subsequently

two or three times; brachials cuneate, short to rather long; pinnules stout; column round; ornamentation finely granular to coarsely vermiculate.

Genotype.—Pachylocrinus tyriensis Wright (Wright, 1937, p. 406, text-figs. 11, 12, pl. xvi, figs. 2, 5, 6; 1939–1940, pp. 21, 22, text-figs. 13, 14, pl. viii, fig. 1, pl. ix, fig. 7, pl. xii, figs. 25, 27).

Scotiacrinus tyriensis (Wright)

Plate IV, figs. 1–3, 7

Holotype.—J. W. Coll., 2265, from No. 1 Bed, Invertiel.

Paratypes.—J. W. Coll., 2266–2271, from Roscobie; 2266 and 2270 (Pl. IV, figs. 1–3, 7).

Horizon.—Lower Limestone Group (Mississippian).

Remarks.—This new genus is proposed to include three species, all of which are characterized by a bowl-shaped cup and arms branching on the first primibrach. In former years these species would have been placed under *Pachylocrinus*, in the broad conception of that genus, and in fact the present species *Scotiacrinus tyriensis* was placed under *Pachylocrinus* in 1937. So far as can now be traced, the nearest described genus to which our forms are related seems to be *Plummericrinus* Moore & Laudon (1943, pp. 56–8, text-fig. 6, pl. 5, figs. 1*a*–*d*). The cup in this genus is bowl-shaped, but the radials are flaring. The arms also branch on the first primibrach. Kirk's definition of the Pachylocrinidae only includes forms with arms branching on the second primibrach (Kirk, 1942, p. 151). Moore & Laudon have extended the family to include *Plummericrinus*. Since *Scotiacrinus* comes near to *Plummericrinus*, both in cup and arm structure, it seems advisable for the present to place it in the same family. As for the present species perhaps its chief character is the rather clumsy arms which are composed of thick and long brachials. The holotype is the only specimen of the species in any way complete and shows the full extent of the arms all round the crown. It has already been figured (Wright, 1937, 1939–1940), but in four other specimens, including the paratype shown on Pl. IV, figs. 1 and 2, traces of the arms can be seen here and there, and all show the same structure.

Scotiacrinus ardrossensis sp. nov.

Plate IV, figs. 4–6, 10

A small species; dorsal cup bowl-shaped and generally similar to that of *S. tyriensis*; IBB sunk in cavity, not so deep as in *S. tyriensis*, small and invisible in side view; plates very tumid, with pits at angles of sutures; one primibrach; arms rather finer than in *S. tyriensis*, composed of shorter cuneate brachials, and branching two or three times; ornamentation finely granular or vermiculate.

Holotype.—J. W. Coll., 2479, from Ardross, near Elie, Fife (Pl. IV, figs. 4 and 5).

Paratype.—J. W. Coll., 2480, from the same locality (Pl. IV, figs. 6 and 10).

Dimensions of Holotype.—Length of specimen over all, 25·6 mm.; height of cup, 5·4 mm.; width of cup, post. to ant., 12 mm.; width of cup, laterally, 11 mm.

Dimensions of Paratype.—Height of cup, 4·7 mm. ; width of cup, post. to ant., 9 mm. ; width of cup, laterally, 8·4 mm.

Horizon.—Calciferous Sandstone Series (Mississippian).

Remarks.—This species is based on two specimens. One is an imperfect crown in which the left posterior ray is partly preserved and traces of two other rays can be seen. The other specimen is a cup. In the collection is also part of another cup. These specimens indicate that this is a small species compared with *S. tyriensis* which occurs on the higher horizon of the Seafield Tower Limestone. The cups in their general shape, size, and normal anal area have some resemblance to the cups of *Phanocrinus calyx* (McCoy), also found in the Seafield Tower Limestone, but they are at once distinguishable by the more tumid character of the plates, the ornamentation, the corrugated sutures, and the little pits between the angles of the sutures. In the holotype (Pl. IV, fig. 4) the left ramus of left posterior ray branches on the sixth secundibrach, the right ramus on the ninth. Probably other branching took place higher up, the structure perhaps not being much different in this respect from that of *S. tyriensis*, although the brachials are relatively shorter. Apart from size, while the cups of both species are very similar, one noticeable difference is the less deep nature of the infra-basal cavity and the finer ornamentation of the plates in the present species.

Scotiacrinus yoredalensis sp. nov.

Plate IV, fig. 8

Cup bowl-shaped and large in relation to arms ; arms more elegant than in *S. tyriensis*, composed of shorter brachials ; cup plates flexed or corrugated at sutures ; sutures between RR and PBrBr gaping ; ornamentation coarse.

Holotype.—Royal Scottish Museum (Nat. Hist. Dept.), 1878—$\frac{11}{658}$ from Yorkshire.

Remarks.—This specimen probably came from the *Woodocrinus* beds of Swaledale, Yorkshire. The limestone matrix is ochrey and not distinguishable from the rock containing so many specimens of *Woodocrinus macrodactylus* de Kon. and other species from the Richmond locality. The label attached to the specimen is marked only " *Woodocrinus expansus* de Kon., Carboniferous Limestone, Yorkshire ". Obviously the specimen does not belong to any species of *Woodocrinus*, and the resemblance of the cup to that of *Scotiacrinus* is at once apparent. In this specimen the cup is very prominent and looks large in relation to the arms, but this may be partly due to the fact that it is slightly squeezed. The ornamentation seems to have been coarse, more so than in *S. tyriensis*, but is in great part worn off, and can only be traced when the specimen is held in a certain light. The anal structure is taken to be the same as in the two previous species since the shape of the cup is similar and two plates which are probably RA and RX can be detected on the extreme left of cup. The radials shown on the cup are from left to right, RPR, RAR, and Ant. R. In contrast to the heavy appearance of the arms in *S. tyriensis* the arms in the Yorkshire species are rather fine. The right anterior ray is nearly complete and is shown in the centre of photograph (Pl. IV, fig. 8).

? *Apographiocrinus scoticus* (Wright)

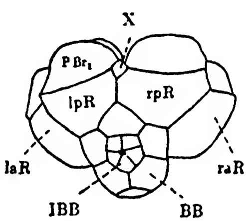
(*Erisocrinus scoticus* Wright, 1942, pp. 275–6, pl. xii, figs. 7–10, 12)
Plate IV, figs. 9, 11, 12, Text-fig. 5

Dorsal cup small, low, conical; IBB for most part sunk in column socket, but outer edges in line with BB and just visible from side; BB small, RR by comparison large, crescentic; R facets not quite full width, the outer edges of RR curving sharply inwards and meeting adjoining RR; small anal X in notch between upper corners of left and right posterior RR; PBr_1 large; PBr_2 axillary and shorter; plates smooth or finely frosted.

Holotype.—J. W. Coll., 2381*a*, from Carlops, Peeblesshire (Pl. IV, figs. 11 and 12).

Paratypes.—J. W. Coll., 2381*b* (Pl. IV, fig. 9), 2381*c*, *d*, *e*, from same locality.

Horizon.—Lower Limestone Group (Mississippian).



TEXT-FIG. 5.—? *Apographiocrinus scoticus* (Wright). Posterior view of crushed cup of holotype from Carlops, × 6 approx.

Remarks.—In the paper cited above the five cups assigned to this species were stated to have no anal plates. Recently, on examining them again, two of the specimens, the holotype and one of the paratypes, appeared to show a small plate between two of the radials. This plate was previously noticed in both specimens, but was not thought to be in place. The two cups have now been further cleaned, and working down between the radials it is now reasonably certain that the plate is the anal X resting in a small notch betwen left and right posterior radials. Some further details of the arm structure have also been noted. It is clear from these two specimens, as well as from a third not figured, that the arms branched on the second primibrach, not on the first. In the top view of holotype (Pl. IV, fig. 12) all the radials have the first primibrachs in position. At the bottom of photograph the upper edges of the first primibrachs are seen, with the axillary primibrachs above them slightly displaced. At the top of photograph the curving upper edges of three radials, LAR, Ant. R, and RAR are shown with the first primibrachs somewhat crushed over on the inside of cup. On LAR the axillary PBr_2 is a little displaced to the right and on RAR the PBr_2 is in position. The small plate in the centre of photograph is probably PBr_2 belonging to the PBr_1 on anterior radial. It is sunk in the matrix. In the paratype (Pl. IV, fig. 9), and another one not figured all the radials show the axillary

nature of the second primibrachs. The other two paratypes have also been cleaned and examined in the light of this new knowledge, including the very small crown referred to the present species (Wright, 1942, pl. xii, figs. 7, 10). This specimen is considerably smaller than the others, and is uncrushed, but so far no anal plate has been detected. The primibrachs are very long in this specimen and are straight on the top indicating that they are not axillary. Two of the primibrachs are surmounted by very small plates (PBr_2), and these may be axillary although it is difficult to judge in such a small specimen. Meantime this crown is grouped with the other specimens, although the apparent lack of an anal plate would suggest that it may belong to a different species. All the other specimens, although larger, are crushed, and it is not easy to assign them to a known genus. Possibly they belong to an undescribed form. The presence of the anal plate in the position indicated appears to debar them from *Erisocrinus* and links them more to genera like *Graphiocrinus*, *Delocrinus*, or even to *Apographiocrinus*. The Mississippian age of our specimens, however, as well as the possession of two primibrachs in the arm structure, seems to preclude them from these genera. At the same time the resemblance in shape of the radials and structure of the radial facets to those of *Apographiocrinus* is very striking. For the present, therefore, the specimens are provisionally referred to this genus, although one cannot exclude the idea that they may also be akin to a genus like *Ampelocrinus*, which has two primibrachs in the arm structure (Kirk, 1942, 22–8, pls. 1 and 2).

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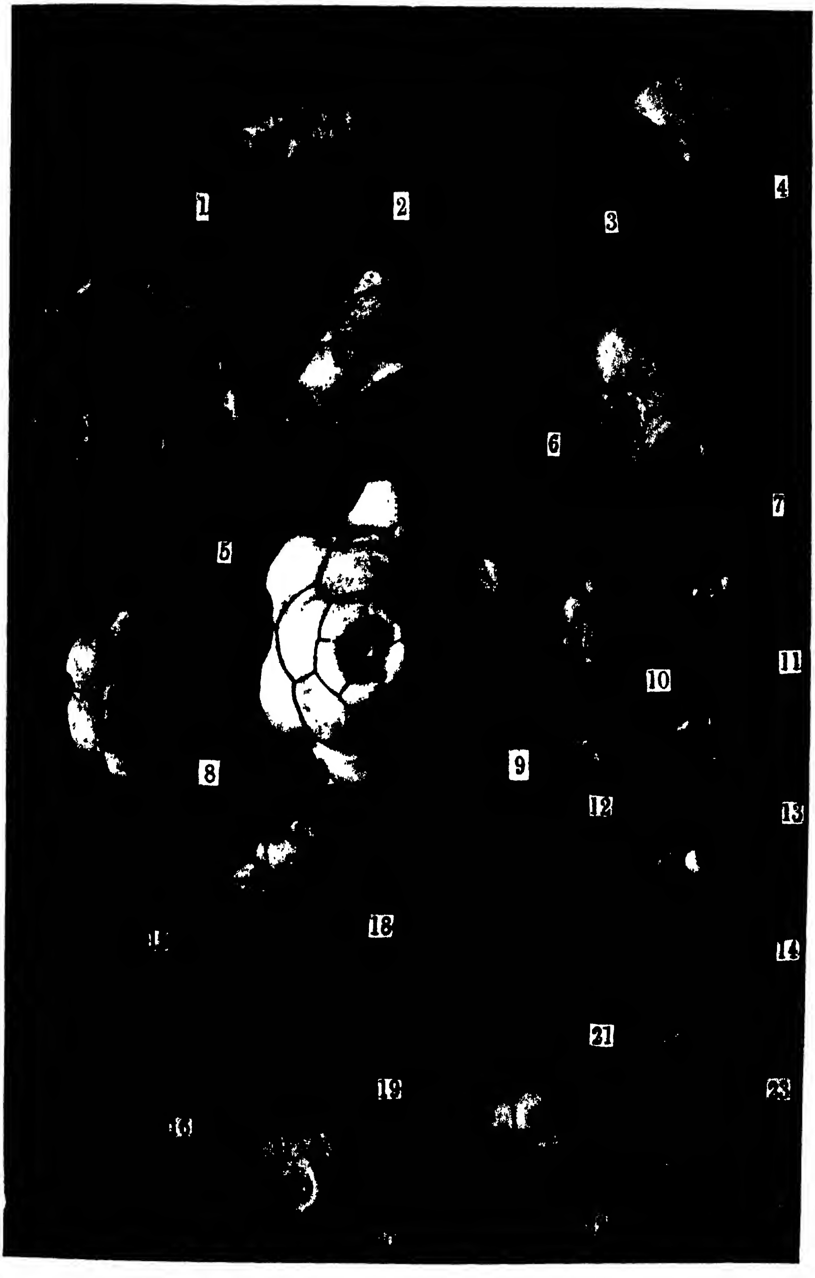
EXPLANATION OF PLATES

(All specimens in the collection of the author unless otherwise stated.)

PLATE II

FIGS. 1–4.—*Hydreionocrinus woodianus* de Kon. from Roscobie ; basal, posterior, ventral, and anterior views of a normal cup, nat. size, 2121.

FIGS. 5–15.—*Aphelecrinus dilatatus* sp. nov. ; fig. 5, ventral view of paratype, 2465, from No. 1 Bed, Invertiel, showing structure of radial facets ; figs. 7 and 10, basal views of same ; figs. 5 and 7, × 2 ; fig. 10, nat. size ; fig. 6, right lateral view of paratype, 2470, from Roscobie, × 2 ; figs. 9 and 15, basal views of same ; and fig. 11, posterior view ; fig. 9, × 2, figs. 11 and 15, nat. size ; figs. 8, 12, 13, and 14, *holotype* (2464),

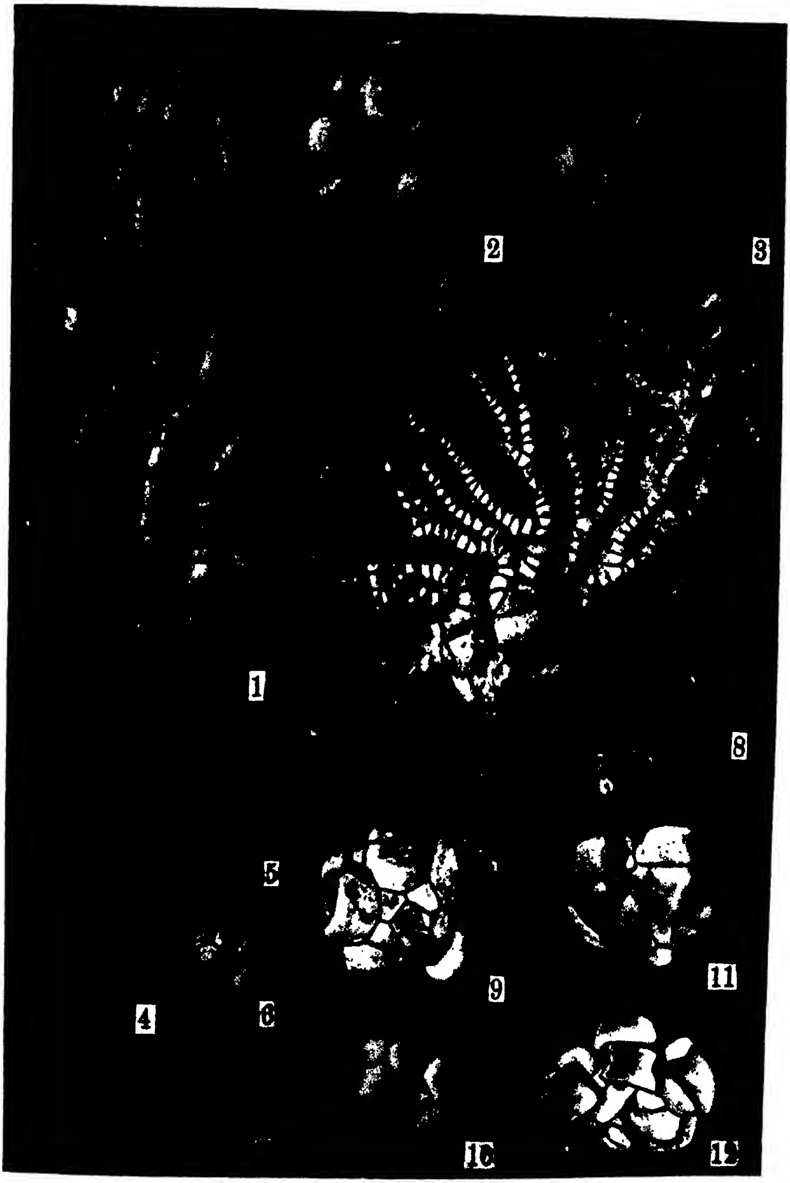


J. Wright Photo.

SCOTTISH CARBONIFEROUS CRINOIDS.

J. Wright Photo.

SCOTTISH CARBONIFEROUS CRINOIDS.



J. Wright Photo.

Carboniferous Crinoids from Scotland and Yorkshire.

from No. 1 Bed, Invertiel; fig. 8, basal view; figs. 12 and 13, anterior views; fig. 14, posterior view; figs. 8, 13, and 14, × 2; fig. 12, nat. size.

FIGS. 16–24.—*Hydreionocrinus artus* sp. nov.; figs. 16, 17, 18, and 19, basal, anterior, posterior, and ventral views of *holotype* (2357) from Seafield Tower Limestone, Seafield, near Kirkcaldy; in fig. 19 the radial facets are somewhat worn; figs. 16, 17, and 19, nat. size; fig. 18, × 1½; figs. 20, 23, and 24, basal, posterior, and anterior views of paratype, 2474, from No. 2 Bed, Invertiel, nat. size; figs. 21 and 22, basal and posterior views of paratype, 691, from Roscobie, nat. size.

PLATE III

FIGS. 1, 6–15, 17, 19, 21, 23.—*Tyrieocrinus laxus* gen. et sp. nov.; figs. 1 and 6, IBB circlets from No. 1 Bed, Invertiel, 2374*a* and *b*; figs. 7 and 12, exterior and interior views of an IBB circlet from Carlops, 1641*a*; figs. 8, 13, and 14, ventral, posterior, and left lateral views of *holotype*, 2477, from No. 1 Bed, Invertiel, × 1½; figs. 10, 11, 15, and 19, left lateral, posterior, ventral, and basal views of *holotype*, nat. size; fig. 9, a displaced cup, paratype 1643 from Seafield Tower Limestone, Seafield, near Kirkcaldy, × 2; fig. 17, IBB circlet, two BB and three RR from Carlops, 1641*b–g*, nat. size; figs. 21 and 23, two radials from Carlops viewed from the top to show facets and thin nature of plates, 1641*h* and *i*, × 2.

FIGS. 2–5.—*Aphelecrinus parvus* sp. nov. from No. 1 Bed, Invertiel; ventral, anterior, posterior, and basal views of *holotype* 1640, × 2.

FIGS. 16, 18, and 22.—*Aphelecrinus roscobiensis* sp. nov. from Roscobie; anterior, basal, and posterior views of *holotype*, 2473, nat. size.

FIG. 20.—A cup of *Cromyocrinus simplex* Trautschold from Russia, basal view for comparison with basal view of *Tyrieocrinus laxus* shown on fig. 19, nat. size.

PLATE IV

FIGS. 1–3 and 7.—*Scotiacrinus tyriensis* (Wright) gen. nov.; figs. 1 and 2, two views of a paratype, 2266, from Roscobie, in fig. 1, part of the cup is seen at bottom of photograph with ventral surface upwards, a primibrach is attached to the radial at right hand bottom corner, the upper part of photograph shows well the character of the arms, fig. 2 is a basal view of the cup, both figs. × 1½; fig. 3, posterior view of paratype, 2270, from Roscobie; and fig. 7, anterior view of same, somewhat tilted, both figs. × 1½.

FIGS. 4–6, 10.—*Scotiacrinus ardrossensis* sp. nov. from Ardross, near Elie, Fife; fig. 4, left posterior view of *holotype*, 2479; and fig. 5, posterior view of same, both figs. × 1½; figs. 6 and 10, basal views of paratype, 2480, from Ardross, fig. 6 × 1½, fig. 10 × 2.

FIGS. 9, 11, and 12.—? *Apographiocrinus scoticus* (Wright) from Carlops; fig. 9, basal view of paratype, 2381*b*, showing anal plate in notch between the two radials on top left of photograph; fig. 11, posterior view of *holotype*, 2381*a*, showing anal plate in notch between the two centre radials and primibrachs in position; fig. 12, ventral view of *holotype*, all figs. × 6.

FIG. 8.—*Scotiacrinus yoredalensis* sp. nov. The *holotype*, Royal Scottish Museum (Nat. Hist. Dept.), No. 1878—$\frac{1}{8}\frac{1}{8}\frac{1}{3}$ (from Yorkshire).

Notes on Some Cretaceous Fossils

By C. W. and E. V. WRIGHT

(PLATE V)

1. *SCAPHITES AURITAS* SCHLÜTER FROM THE *HOLASTER PLANUS* ZONE OF SURREY

THE only species of *Scaphites* hitherto identified from the *Holaster planus* Zone of England is *S. geinitzi* d'Orbigny, which occurs commonly both in the Chalk Rock and in the normal facies of the zone in many parts of the country.

Recently we found in some chalk collected by Mr. S. C. A. Holmes, from the *Holaster planus* Zone of the southernmost cutting of the Mickleham By-pass, in Surrey, a well-preserved specimen of a compressed form of this genus with prominent lateral lappets. A second specimen was subsequently found among material collected by us some years before from the same horizon on the Guildford–Godalming By-pass.

These two specimens clearly belong to Schlüter's *Scaphites auritus*, which was described from rather poor specimens from the " Scaphiten Pläner " of Germany (4). The species was also figured and described as new in the same year by Fritsch and Schloenbach from the equivalent horizon in Bohemia (2), but most of their specimens were little better than the types. Since the species may be new to the majority of British geologists, and the English specimens are well preserved, we give a full description.

Scaphites auritus Schlüter, Plate V, figs. 1 and 2

April 1872 *Scaphites auritus* Schlüter, " Ceph. ober. deutsch. Kreide, Palaeontographica," xxi, lief 4, pl. xxiii, figs. 5–9.
1872 *Scaphites auritus* Fritsch and Schloenbach, " Ceph. böhmischen Kreide-formation," Prague, pl. xiii, figs. 8, 9, 11, 14, 15.

Description.—A small species with compressed whorl-section, the sides of the hamus being distinctly flattened ; compared with typical *Scaphites* (*Scaphites*), for example, *S. aequalis* or *geinitzi* d'Orb., it is very evolute ; the umbilical edge of the hamus forms almost a simple curve in continuation of that of the inner whorls ; the apertural margin is strongly folded and has a slight ventral projection and prominent lateral lappets, which may extend so far as to overlap the inner whorls. The inner whorls have strong, bifurcating sigmoid ribs with a forward bend on the periphery ; on the hamus the density of the ribs increases, and they tend to degenerate almost to striae. There are usually no tubercles, though the original of Schlüter's pl. xxiii, figs. 5 and 6, has small umbilical bullae. The profile of the hamus as is shown in fig. 2 is not an even curve, the periphery being made up of a series of straight lengths. The suture line does not appear to differ from that of a typical *S. geinitzi* d'Orb.

The measurements of the two Surrey specimens are as follows :—

Author's coll.	*Length.*	*Height.*	*Diam. at last septum.*	*Whorl height at last septum.*	*Thickness at last septum.*	*Thickness at aperture.*
No. 14813 .	22	19	14	6	4	7·5 mm.
No. 14079 .	20·5	17·5	13	5·5	4·5	7·5 mm.

Affinities and Differences.—*S. auritus* Schlüter is readily distinguished from any other British species of the genus by its bifurcating sigmoid untuberculate ribs and by its prominent lateral lappets. The only other species to which it appears to bear much resemblance is *S. planus* Roman and Mazarin (4). This has a whorl section like that of the present species, but the figures are too bad for its other characters to be assessed.

S. auritus Schlüter is so different from other *Scaphites* that it might well be placed in a separate subgenus, ranking with *Discoscaphites*, *Acanthoscaphites*, etc., instead of being retained in *Scaphites* (*Scaphites*), where it was placed by Nowak (4) and Reeside (5). We do not, however, feel justified at present in adding to the already extensive list of generic and subgeneric names of *Scaphites.*

It is, however, noteworthy in this connection that one of the specimens figured by Fritsch (2) (pl. 14, fig. 12 only), although it has lateral lappets, is involute and moderately inflated, while the ornament is comparable with that of the more finely ribbed forms of *S. geinitzi* d'Orb. Without seeing the actual specimen it is difficult to be certain of its affinities, but it would appear that this particular example should be regarded as a lappeted mutation of *S. geinitzi* d'Orb.

Little attention need be paid, except in so far as it throws light on the form of the species, to Fritsch's statement (2, p. 44), "Es ware nicht unmöglich, dass dies zarteren Formen *Sc. rochatianus* und *auritus* die Mannchen zu den voluminoseren weibchen *Sc. aequalis* und *geinitzi* gewesen sind."

Range and Localities.—*S. auritus* Schlüter occurs in the lower part of the *Holaster planus* Zone of the Mickleham and Guildford By-passes in Surrey, in the "Scaphiten Planer" of Germany (2) and Czechoslovakia (2 and 3), and in the upper Turonian of North-East France, *fide* Barrois (1).

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2. Opercula of the Gastropod *Neritopsis* from the Upper Chalk

The small calcareous objects figured on Plate V, figs. 3 and 4, have long puzzled us. Recently our doubts were resolved on noticing in Wenz (2) figures of similar objects from Jurassic rocks, stated to be the opercula of gastropods of the genus *Neritopsis*. They have been described variously as *Peltarion* Deslongchamps, *Cyclidia* Rolle, *Scaphanidia* Rolle, and *Rhynchidia* Laube.

These opercula are calcareous bodies forming roughly a rhomboid with indentations in two sides, but details of the complex form can only be conveyed by illustration. The substance is lamellar, but certain surfaces have a hard smooth outer layer, which is well seen at the top of Pl. V, fig. 3*a*.

The larger of our two specimens (No. 13449) comes from the Senonian *Micraster coranguinum* Zone of Wanborough in Surrey, and the smaller one (No. 14165) from the (restricted) *Actinocamax quadratus* Zone of East Harnham, near Salisbury. It is probable that there are specimens preserved in various collections which have gone unrecorded.

Cossman (1) quotes *N. laevigata* d'Orb. from the Campanian of France, and *N. allaudiensis* Cossm. and *N. abbatei* Fourteau from the North African Senonian. There is, however, nothing to show whether or not our specimens belong to any of these species. We are not aware of any specimen of *Neritopsis* having been found in the English Upper Chalk.

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(2) Wenz, W. *Handbuch der Paläozoologie*, vol. 6. 1. "*Gastropoda*," Part 2, 1938, p. 412.

3. A Box Crab (*Calappa cranium* sp. nov.) from the Cenomanian of Wilmington, Devon

The specimen under consideration is a carapace of a species of small crab from the Cenomanian Limestone of Wilmington, between Honiton and Axminster, in Devon, a prolific horizon and locality that has yielded over two hundred species of invertebrates, including at least six species of crabs. Our single specimen was found in 1936, but no further examples have since come to light, and as this is the first Cretaceous representative of its genus to be discovered we have decided to place it on record.

Family.—Calappidae.

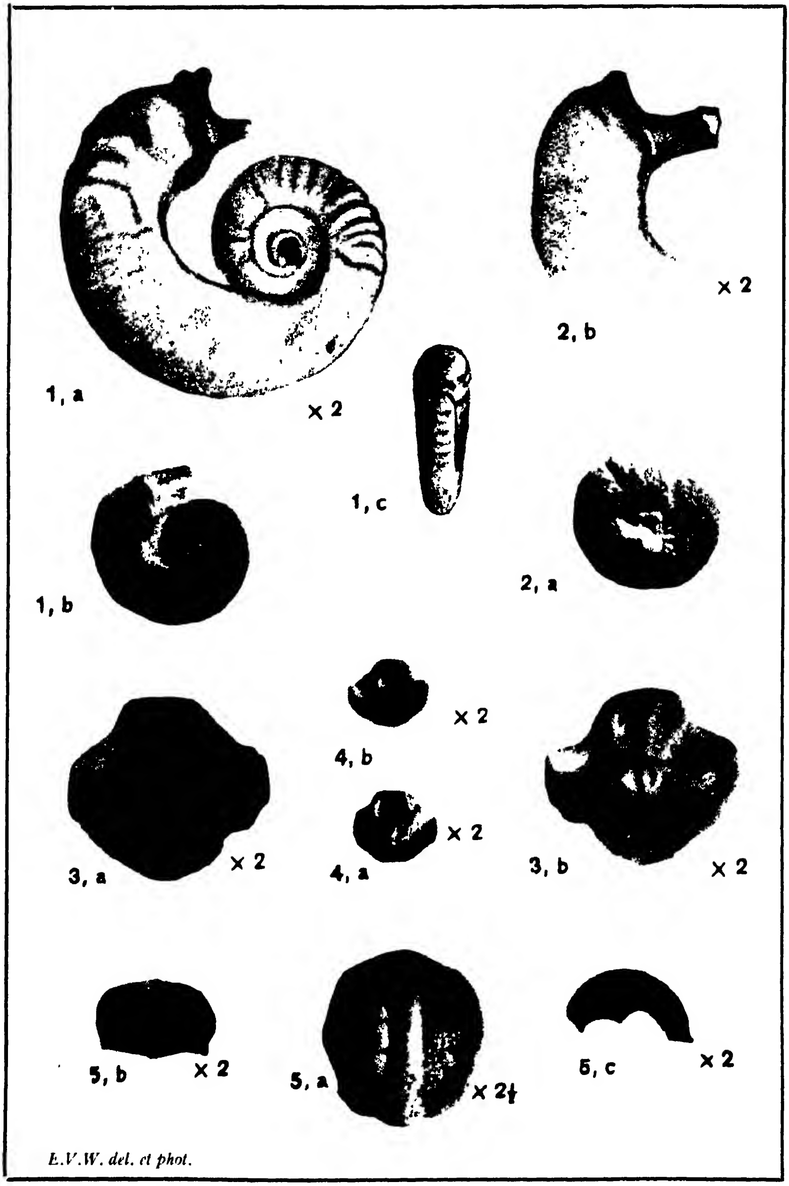
Genus.—Calappa Weber 1795.

Calappa cranium sp. nov., Pl. V, figs. 5*a–c*

Type.—The holotype is No. 3506 in the authors' collection.

Description.—Internal cast, with fragments of test, of a globose carapace, as broad as long, and nearly square when viewed from above. A ridge of rounded section and regular width, bounded by a slight furrow on either side, runs from front to rear, giving the profile a resemblance to the type of steel helmet worn by the French Army. This ridge or crest, characteristic of the family, expands very slightly posteriorly. It forms a slight projection on the posterior margin. In side view the carapace is almost semicircular, though it slopes a little more steeply in front than behind. From the front it appears as if built of two quadrants separated by the median ridge which occupies about one-seventh of the total width. The lateral margin has a double indentation to accommodate the appendages. The test appears at first sight to be smooth, but is ornamented with very fine though sparse granulation.

Above the orbits, which are indistinct in our specimen, there are slight but noticeable bulges, contiguous with the median ridge. There are also



SCAPHITES, NERITOPSIS AND CALAPPA.

bulges of similar proportions projecting from the ridge a third of the distance from the front, from the side of which spring a pair of dichotomosing thread-like lines. Similar lines occur also on each side of the median crest two-thirds of the distance from the front. There are two small but distinct tubercles, one on each side of the expanded posterior end of the median crest.

Remarks.—The genus *Calappa* is represented by a succession of forms from the Eocene to the present day, but we are not aware of any Cretaceous member of the genus or of *Calappilia*. *C. cranium* is characterized by its subdued ornamentation, its globose helmet shape, and the absence of projecting spines at the postero-lateral corners.

Horizon and Locality.—*C. cranium* was found in the small pit north-east of Wilmington on the lane leading to Hayne's Farm. The exact horizon in the pit is not known as the specimen came from the talus, but from its matrix it appears to be from the limestone bed with *Mantelliceras* spp., *Hyphoplites crassofalcatus* (Semenow), and *Forbesiceras largilliertianum* (d'Orb.), that is the upper part of the lower Cenomanian.

EXPLANATION OF PLATE

1. *Scaphites auritus* Schlüter. *Holaster planus* Zone, Mickleham By-pass, Surrey : (*a*) side view, × 2 ; (*b*) side view, natural size ; (*c*) apertural view (Authors' Collection 14813).
2. *Scaphites auritus* Schlüter. *Holaster planus* Zone, Guildford and Godalming By-pass, Surrey : (*a*) side view, natural size ; (*b*) side view of aperture, × 2 (Authors' Collection 14079).
3. *Neritopsis* sp. *Micraster coranguinum* Zone, Wanborough, Surrey : (*a*) outer and (*b*) inner views, × 2 (Authors' Collection 13449).
4. *Neritopsis* sp. *Actinocamax quadratus* Zone, East Harnham, Wiltshire : (*a*) outer and (*b*) inner views, × 2 (Authors' Collection 14166).
5. *Calappa cranium* sp. nov. Cenomanian, Wilmington, Devon : (*a*) top view, × 2½ ; (*b*) front ; and (*c*) side views, × 2 (Authors' Collection 3506)

Contemporaneous Disturbances in Lacustrine Beds in Kenya

By P. E. Kent

(PLATE VI)

IN the course of an examination of Lower and Middle Pleistocene Beds at Kanam and Kanjera, on the southern shore of the Kavirondo Gulf of Victoria Nyanza, exposures of strongly disturbed lacustrine beds were located. The remarkable character of the deformation, at a locality where the possibility of a compressional origin could be excluded, led Professor P. G. H. Boswell (with whom the occurrence was discovered) to suggest that a short account should be published.

The lacustrine beds were deposited in an extended Lake Victoria around Homa volcano, which was active at the time of their deposition, and contributed largely to their formation. An account of the stratigraphy has already been published (Kent, 1942).

The disturbed strata described below are found in the Lower Pleistocene Kanam Beds, and in the overlying Lower/Middle Pleistocene Rawe Beds. The Kanam beds consist of alternating clays and ash beds, with local agglomerate lenticles and streaks of gravel. The most striking disturbances were in the upper part of this series at Kokkoth (two miles north-east of the northern summit of Homa), where 20 feet or more of pinkish brown clays interbedded with fine laminated ash are overlain by 3 feet of sandstone and gravel, and by 10 feet of yellowish clays. These are succeeded by the Rawe Beds, which include sandy clays with sandstone streaks, and a large proportion of silty shales and siltstone with clay partings. At Kokkoth the Rawe Beds were horizontal and undisturbed, in contrast to the beds beneath, but interesting disturbances were seen to affect them at an exposure a mile to the south.

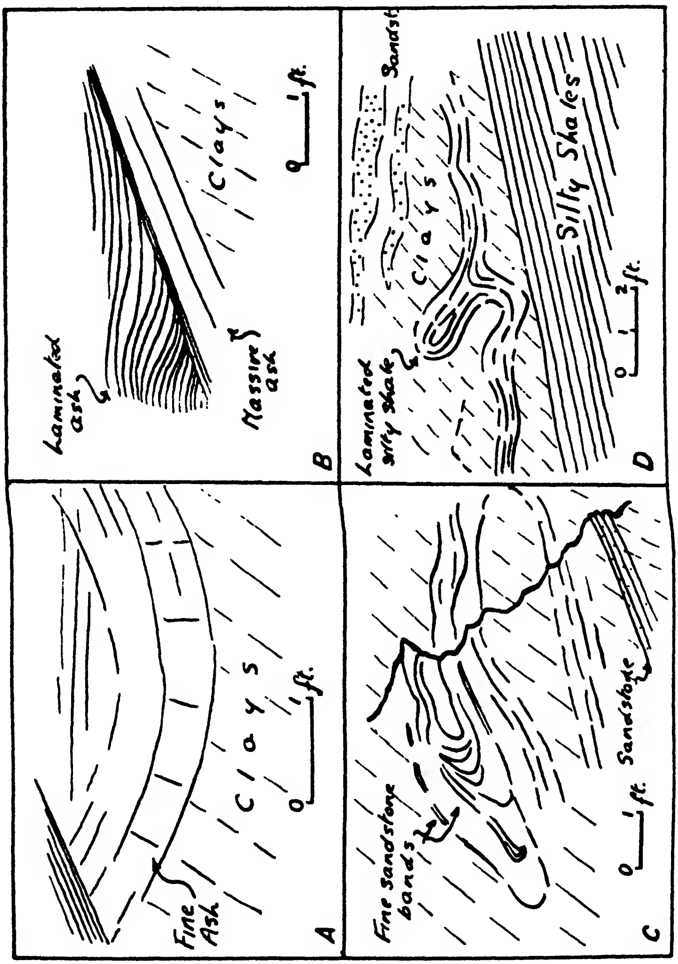
Description of Structures

As the distribution and the variation in complexity of the structures at Kokkoth was quite irregular, it is most convenient to describe them by types rather than in relation to their geographical positions.

The simpler structures seen were shallow anticlines and synclines affecting the ash beds, the wave-length varying from 3 to 20 feet in different cases. In some of these the folded beds were seen to be truncated by horizontal overlying beds ; in other cases normal horizontal sedimentation had filled the troughs (Text-fig. 1A). The laminae commonly thickened in the troughs so that the amplitude of the folding decreased upwards ; this was in some cases probably due to slow development of the fold without interruption of sedimentation, in other cases the folding was associated with tectonic thickening (Text-fig. 1B).

At first glance the sudden changes of dip of the laminae appeared similar to current bedding, but the similarities disappeared on closer inspection, and it was also evident that the exceedingly fine grained ash (approaching clay grade) could not have been deposited in currents strong enough to produce such wide channels. The development of simple anticlines in association with the synclines confirmed belief in the tectonic origin of the features.

Forty yards west of a later neck of agglomerate which had pierced the beds [1] much sharper folding was developed in a foot-thick bed of fine laminated ash (Pl. VI, fig. A). This bed had laminae of an average thickness of a quarter of an inch, which now have the strength and brittleness of a biscuit. In it sharp folding had developed, the most



TEXT-FIG. 1.—Examples of Disturbances in the Pleistocene Beds of Kavirondo, Kenya.

acute fold measuring 11 inches high by 3 inches long, and this development was associated with a certain amount of shearing. The finer laminae had tended to break when sharply folded, but the thicker ones had yielded entirely by flexing, with some thickening on the fold crests. The

[1] The post-depositional date of the neck was shown by the absence of agglomerate interbedded with either the Kanam or Rawe beds in the immediate vicinity.

bedding planes here and in other folds were marked by two sets of striae, a fine very regular set parallel to the fold axes, and a more irregular set at right angles ; the first was probably caused by wrinkling of the surfaces of the flexing laminae and the second by adjustment flow. Ferruginous streaks and racy bands in the overlying clay suggested that the ash was not unique in its deformation, although details of the folding could not be clearly seen, and an ash bed at a lower level which was overfolded towards the south formed the core of a larger fold traceable in the clays from a persistent ferruginous band.

It was sufficiently obvious that such sharp folding could not have been imposed on the laminated ash in its present consolidated condition, and that it must have been plastic when deformed. An indication of how nearly contemporaneous was the disturbance was seen a few yards away, where an ash of the same group of beds was seen to form part of a fold which had been truncated and buried by deposition of a similar stratum.

In a number of places exposures of the ash showed broader anticlinal folds with dips of 10–30 degrees, affecting 1–3 feet of beds. Several of these had their axes vertical, and their early date was indicated by the fact that their folding had preceded induration. One structure of this kind was a broad fold, on which were superimposed minor crumples with a wavelength of about 1 inch. The latter may have resulted from the particularly fine lamination here developed in the stratum, which divides it into leaves $\frac{1}{80}-\frac{1}{10}$ inch in thickness.

More characteristic than the symmetrical structures were recumbent folds, the most remarkable disturbances of the series. In the largest of these a bed of coarse ash (cemented so hard as to need a heavy hammer blow to break it) was seen to form the core of a nappe-like structure (Pl. VI, fig. B). The central ash bed was doubled upon itself for at least 18 feet horizontally. A finer poorly laminated ash bed separated from the central core by a few feet of clay could be traced round the fold except for a short break at the nose, and a third ash bed and brown sandstone, which were further separated from the core and from one another by brown clays, showed parallelism above and below. There was thus a flat-lying overfold measuring at least 30 feet long and 8 feet thick, and possibly as much as 50–60 feet long and 25 feet thick.

A sandstone at a higher level further east showed comparable structures. At a locality where it was relatively thinly developed and was interbedded with sandy clay it had been flexed into a flat-lying double fold 10 feet long, which involved a thickness of 3 feet or more of beds (Text-fig. 1c). The immediately underlying beds were quite free from folding, but showed a dip of 20 degrees in the same direction as the overfold. Higher beds seen nearby were without deformation.

Further east the sandstone was coarse and ashy, and was again strongly disturbed ; at one point a fold had been truncated by erosion before resumption of deposition. Another flat-lying overfold in the sandstone was seen in an isolated exposure near the eastern end of Kokkoth cliff ; this had a core of soft ferruginous sand surrounded by coarse micaceous ash, buff clay, and by a second thin ash bed. The central beds had flexed without breaking, but the outer ash was broken at the nose of the fold.

In all these cases at Kokkoth the folding had affected the Kanam beds

only, and wherever the overlying Rawe beds were seen they were undisturbed and flat-lying. At two other localities, however, contemporaneous disturbances were seen to affect the Rawe beds.

The first was at Kanam " Fish Cliff" ; here an exposure of the base of the Rawe series showed that a thickness of about 3 feet of thin sandstones interbedded with sandy clay had been strongly contorted and fractured, so that within this thickness all trace of the original sequence was obliterated. The Kanam beds were not exposed immediately beneath, but a few tens of yards away they were undisturbed. The contorted beds were directly covered by a hard laminated siltstone bed which was horizontal and without a trace of folding. This was succeeded by the normal Rawe series. Here the deformation was unaccompanied by tilting of the substratum, in this respect closely resembling a case of contorted beds seen in similar deposits of the Middle Pleistocene (Bed 4) of Oldoway, Tanganyika.

The other example of sliding in the Rawe beds was seen in the wall of a ravine (" Red Gully ") a mile south of Kokkoth cliff (Text-fig. 1D). The lower part of the main section showed hard silty shales and thinly bedded fine sandstones dipping evenly towards the north at 20 degrees. Above were banded clays containing a bed of laminated cemented silty shale about 1 foot thick, and more massive sandstone beds 2 or 3 feet higher. The clays had evidently slipped on the slope of the underlying shales, and with the interbedded silty shale had become contorted and overfolded in the process. A strike section seen a short distance to the south in the same slipped mass showed in the lower part a bed of hard shale which had both sides turned underneath, and was probably a lobe-like overfold seen in cross-section. Higher up was a similar bed of hard shale—possibly the same bed overfolded at a higher level—and at the top of the section were beds of sandstone similar to those capping the dip section.

It was at first thought that these were recent structures, as the higher parts of the folded beds were much fractured. Closer examination showed, however, that the fracture was due to weathering, that the folded beds deeper in the section were not similarly affected, and that they must have been flexed before cementation—probably soon after deposition. The horizontality of the capping sandstone at the top of both parts of the section confirms the contemporaneous nature of the movement, and indicates that the slipped mass had either been planed off, or had virtually filled the contemporary depression, and that normal horizontal sedimentation had subsequently been resumed.

The Origin of the Disturbances

The study of the beds at Kokkoth showed that the disturbances were irregularly distributed, sometimes in groups, sometimes singly, and that their complexity did not vary regularly along the line of section. The strike of the folds was also irregular, varying from E.–W. in some simple anticlines to N.–S. in flat-lying folds.

The stratigraphical circumstances show that the disturbed beds had never been loaded to such an extent that flow of fully consolidated and cemented sediments could take place, for the overlying deposits are unlikely ever to have been more than 200 feet in total thickness and may have been much less. The sediments had, however, probably suffered

partial loss of the initial water content before disturbance, for they were soft and plastic without being fully fluid so that individual laminae maintain their identity and thickness despite flexing. They were, however, in general too soft at the time of deformation to yield pebble beds or grit streaks when erosion occurred.

The early date of all the movements is shown by the sharp folding of beds now too brittle and cemented to flex without fracture. In addition, the rapid variation in thickness of fine-grained beds in some of the simpler folds, and the truncation of some structures by later beds showed that part of the movement was truly contemporaneous with deposition. In other cases it is clear that some feet of sediment accumulated by the time that sliding occurred, and the disturbance is better described as pene-contemporaneous. The close similarity of the faunas of undisturbed beds above and below (both dateable as late Lower Pleistocene) shows that there cannot have been any prolonged pause, and that the whole process of deposition, partial compaction, and sliding was complete within say ten thousand years.

The mechanism by which the flat-lying overfolds developed is somewhat difficult to understand, particularly in the case of the structure measuring more than 30 feet in length. It seems hardly likely that the drag of a superimposed sliding mass could have produced this effect without fracturing, and the evenness of the fold seems to indicate a force applied equally to all parts of it, a force which could hardly be other than gravity. One may, therefore, imagine that the slipping of a plastic sheet of partly consolidated sediments over a tilted surface of hardened beds led to the formation of a sharp anticline which rose a short distance, became first asymmetrical, and then overfolded, but still continued to develop, and moved as a doubled fold to form the present structure. The unusual and striking character of the folding seems to be due to the abnormal tensile strength of the sediments while they were still in a plastic state, which permitted strong folding with a minimum quantity of fracturing.

It is notable that in all cases that could be fully investigated the movement had taken place mainly on the basal plane of the unconsolidated deposits and only rarely is there shearing within these beds (contrast Hadding, 1931, p. 378). The sharp lithological variation within the series had produced an alternation of beds of markedly different mechanical characteristics, with consequent encouragement of movement of sheets of sediment independently of more consolidated beds beneath.

In the cases of Kokkoth and Red Gully, where the immediately underlying beds are clearly seen, the collapsed mass is lying on an inclined surface. In the Red Gully exposure the horizontality of the capping sandstone shows also that the dip was wholly produced at the time of the sliding, and has not been increased to any significant extent since that time. It is evident that the collapse in these cases is due to contemporary earth movement (tilting) which took place much more rapidly than the rate of consolidation of the sediment; a case which Hadding (*loc. cit.*, p. 380) thought unlikely to arise. They thus constitute a special and unusual type of slide phenomenon.

The stratigraphical evidence shows that the most extensive sliding took

FIG. 1.—CONTORTED VOLCANIC ASH IN LOWER PLEISTOCENE BEDS, KENYA.

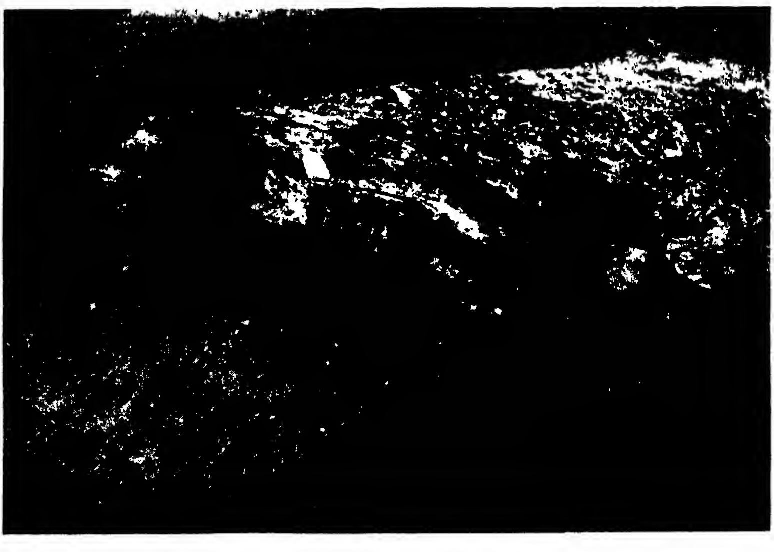


FIG. 2.—RECUMBENT FOLD IN BEDDED VOLCANIC ASH, KENYA.

place in this district during the final stages of deposition of the Kanam Beds, and that more local sliding took place soon afterwards while the Rawe beds were being laid down. The periods when these movements took place were relatively free from explosive eruption, which led to the deposition of extensive agglomerates at other times. The sliding took place, however, at about the time of extrusion of the most widespread of the Pleistocene lava flows from Homa, and may well have been consequent on collapse associated with lava extrusion.

The horizontal layer of broken contorted beds at Kanam Fish Cliff is evidently different in origin, for the substratum of the disturbed beds is still horizontal and there is no evidence of appreciable lateral movement of the material. The disturbances resemble some of those figured by Miller (1922), on the origin of which there has been much controversy. In the present case there is no possibility of differential movement of the beds above and below as was suggested for some of these American examples, and the disturbances are much less regular than would be expected in such a case. The disturbances might also be compared with some of those of the Ordovician of Girvan which Henderson has described and attributed to earthquake action (1935, p. 503). In this particular case, however, although the deformation could be visualized as due to propagation of a violent earthquake wave through partly consolidated sediment, the complete absence of disturbance in the same bed a few hundred yards away tends to exclude this explanation (although it may apply to the rather similar contorted bed at Oldoway mentioned above). The cause must have been local, and was not connected with tilting or subsidence ; it seems most likely that the beds were disturbed by thrust transmitted from a landslide on the neighbouring slopes of Homa volcano ; the beds having been planed off after disturbance and the slipped ground removed by subsequent erosion.

It may be noted that there is no evidence of the action of " tunamis " (tidal waves) which have been considered by Bailey (1932, p. 450) and others to be an important factor in other cases of contemporaneous sliding. The bevelling of the surface of the disturbed beds in each of the above-mentioned cases may be regarded as due to normal scour of the lake floor where the crumpling has brought soft sediments within reach of wave and current action.

Thanks are due to Professor P. G. H. Boswell and to Dr. S. M. K. Henderson for reading the manuscript of this paper and for making a number of helpful suggestions about the presentation of the data.

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EXPLANATION OF PLATE

FIG. A.—Contorted Volcanic Ash in Lower Pleistocene Beds, Kenya.
FIG B.—Recumbent Fold in Bedded Volcanic Ash, Kenya.

CORRESPONDENCE

LOWER ORDOVICIAN TRILOBITES

SIR,—Since the March–April number of this Magazine was issued my attention has been drawn to a recent paper by F. Rasetti in the *American Journal of Science* (vol. 243, January, 1945) on the genera *Loganopeltis* and *Loganopeltoides* with a description and figure (p. 40, pl. 1, fig. 7) of the pygidium of his new species *Loganopeltis depressa* from the Lower Ordovician of Quebec. It seems to be almost identical with the specimen from the Shangort beds of Tourmakeady which was referred with considerable doubt to the genus *Cybelopsis* (*Geol. Mag.*, 82, 1945, p. 60), so that the generic reference may be altered to *Loganopeltis* with confidence.

F. R. C. REED.

SEDGWICK MUSEUM,
CAMBRIDGE.
15th May, 1945.

ON THE NORMAL FAULTING OF RIFT VALLEY STRUCTURES

SIRS,—In his recent very interesting paper on the above subject (*Geol. Mag.*, lxxxii, 1945, 37–44) Mr. H. G. Busk urges, rightly I believe, that normal faulting has played a greater part in rift tectonics than is often conceded. There are, however, certain of his statements on which I should like to comment.

On p. 42 he states that the rift valley movements were initiated on a broad peneplain ; this peneplain is held to be of vast extent, and to include the great peneplain of the Northern Frontier District of Kenya.

While it is true that a great peneplain, usually referred to as the Miocene peneplain or the main peneplain, did extend over that part of Africa occupied by the Rift Zone, insufficient allowance has been made for the very large number of residuals and peneplain remnants that rest upon its surface in many areas. These remnants sometimes give rise to strong relief, and they are in places bounded by scarps eroded along ancient faults ; such scarps (fault-line scarps) have sometimes been confused with Rift Valley fault-scarps. In the southern Rift zone at least there occur fault-line troughs, such as the Luangwa Valley, that have the form of the Rift Valleys, but long antedate them. Before progress can be made in the formulation of Rift theories based on scarps and plateaux, it is first necessary clearly to distinguish the true Rift scarps from the numerous other scarps of different age and origin.

The nature of a very large number of the Rift faults does not appear to be essentially different from that of the pre-Rift (post-Karroo) faults, which have always been accepted as normal faults, apart from some rare local disturbances.

Mr. Busk regards the great peneplain of the Northern Frontier District of Kenya as part of the main peneplain ; it belongs, however, to a much younger cycle, which is separated from the main peneplain by scarps, up to 1,000 feet in height, that are usually erosion scarps, but sometimes possibly fault-line scarps. The main peneplain is represented by the southern Abyssinia plateau and the Uganda (Karamoja) peneplain.

Instead of an era of immobility followed by gentle movements, as described by Mr. Busk, I suggest that the features of the Rift Zone are due very largely to prolonged but intermittent continental uplift and consequent erosion, interrupted by two main periods of faulting—the post-Karroo and the Rift.

Great isolated mountains such as Ruwenzori and certain lesser heights are to be regarded in part, I suggest, as the cores of great residuals due to this long-continued uplift, and bounded locally by ancient faults.

Finally, in the north-eastern part of the Northern Frontier District, Mr. Busk has referred to certain isolated hills as horsts that rose above the Jurassic sea, and he quotes them as evidence for Jurassic block-faulting in this area. These views are based on the assumption that the red sandstone hills in question are older than the surrounding Jurassic limestones; but actually the red sandstones (Marahan Sandstones) succeed the limestones by way of a well-defined transitional zone of alternating limestones and sandstones, as is clearly displayed in excellent sections along the westward-facing scarps. There may be faulting in the area, but the topography is due essentially to normal dip and strike structures in gently-folded sediments and to the presence of high, steep-sided outliers of the resistant Marahan Sandstones resting on the limestones.

F. DIXEY.

GEOLOGICAL SURVEY DEPARTMENT,
KADUNA JUNCTION, NIGERIA.
7th May, 1945.

A JURASSIC OUTCROP IN THE JORDAN VALLEY

SIRS,—In your issue of March–April, M. Avnimelech described an interesting discovery of Jurassic rocks from a new locality in the Jordan Valley, but I should like to register disagreement with the deductions which he draws therefrom. He suggests that the incompleteness of the Upper Jurassic succession in the Yabbok area may be due to movements in Callovian times forming a local domal uplift, whereas I would prefer a more regional explanation. A short distance further south marine Triassic beds are present in Wadi Hesban and Wadi Ayun Musa [1] but, in this locality, only continental "Nubian" sandstone occupies the interval between Triassic and Cenomanian. Further south again along the eastern shore of the Dead Sea south of Wadi Zerka Ma'in there are no marine intercalations in the Nubian Sandstone between Cambrian and Cenomanian.

My explanation of these facts is that the shore lines of the Triassic, Jurassic, and, perhaps, Lower Cretaceous seas had a direction approximately parallel to the present Palestine coast and they crossed obliquely what is now the Jordan Valley at, or in the neighbourhood of, the northern end of the Dead Sea. These lines mark the limit of the marine transgressions of these periods and further east-south-eastward continental conditions prevailed over an immense range of time. In 1931 I suggested,[2]

[1] Cox, L. R., "Further Notes on the Trans-Jordan Trias," *Annals and Mag. of Nat. Hist.*, Ser. **10**, vol. x, 93–113, 1932.

[2] Lees, G. M., "Salt. Some Depositional and Deformational Problems," *Journ. Inst. Pet. Tech.*, 1931, ix, p. 267.

as one possibility, a Triassic age for the salt of Jebel Usdum at the south-west corner of the Dead Sea, basing my idea on a study of the palaeogeography of the region which I illustrated by a map showing shore-lines.

The area at the north-east corner of the Dead Sea is of exceptional geological interest from many points of view and deserves much more detailed study than has been given to it hitherto. I hope that M. Avnimelech may be stimulated to undertake it himself. In the interests of accuracy of record I should like to point out that the Yabbok Valley is incorrectly marked on his sketch map as the "Yarmuk R." I can confirm his statement that the fossils described by L. R. Cox in 1925 were from the Yabbok Valley but close to the point of its debouchment into the Jordan Valley. The outcrop of Jurassic extends for some distance south of the Yabbok along the flank of the Jordan Valley, that is, in the direction of the new locality now recorded.

G. M. Lees.

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AN INDICATOR OF WATERFLOW IN CAVES

Sirs,—The following abstract of a larger paper which I am preparing on the subject of those curious interconnected hollows seen on the walls, roofs, and floors of many caves may be of interest to speleologists.

The pattern often referred to as "honeycomb", "oyster-shell," etc., is termed by some U.S.A. geologists, "flutes." [1] It is also observed in surface streams and rivers, but in the absence of sub-aerial weathering, it is best developed in caverns. I have proposed the term "pocket" to describe these forms and "pocketing" the process, as the American term "flute" and "fluting" is apt to be confused with long groovings (e.g. near waterfalls).

Pocketing is the result of directional waterflow of high velocity causing a complex of vortices under certain conditions. These vortices, helped by the abrasional power of the stream load and in the case of limestone also by solution, tend to scour out asymmetrical pockets with a steep side invariably upstream and a broader surface (usually ending in the apex of a triangle) downstream. Variations in stream velocity and redistribution of the vortices cause overlapping of pockets, etc.

Tubular-sectioned cave passages, pocketed on walls, ceiling and floor, postulate a completely water-filled passage, often under hydrostatic pressure flow. Thus pockets are known to indicate an *upgrade* flow in some caves.

The chief interest of pocketing to the speleologist is that it provides a means of plotting the direction of waterflow in dry stream-deserted passages and caverns; that is if pocketing is present and not obscured by dripstone, etc.

The following rules will help to establish the direction of waterflow which formed the pockets :—

[1] Bretz, J. H., "Vadose and Phreatic Features of Limestone Caverns," *Journ. Geol.*, 1 (1942), 675–811.

1. If, standing close to a pocketed wall and looking along the face, a series of roughly triangular " peaks " is seen, you are looking *downstream.*

2. If the view is a series of wavy ridges with almost complete absence of points, you are looking *upstream.*

3. A pocketed surface looked at in plan with a light held close to the surface and pointing downstream, will show a series of bright faces, outlined by dark ridges. The steep upstream " scarps " of the pockets are in shadow.

4. The same surface looked at with the light in the opposite direction gives a dark pattern picked out by the now brightly illuminated upstream scarp edges of the pockets.

Another helpful point, when in doubt, is provided by cross-sections of a number of individual pockets. The different aspects of pocketing under Nos. 3 and 4 can be successfully photographed. A curious optical illusion is often seen in plan photographs of pocketing ; instead of pockets one is inclined to see convex forms.

I have tried out directional plotting in a number of active and non-active cave systems in Ireland.

J. C. COLEMAN.

39 UPPER JOHN STREET,
CORK, EIRE.
January, 1945.

REVIEWS

MAPA GEOLOGICO PRELIMINAR GENERALIZADO DEL PERU. Scale 1 : 8,500,000, with explanatory memoir. By J. A. BROGGI. pp. 14, with folding coloured map. Instituto Geologico del Peru. Lima, 1945.

MAPA GEOLOGICO GENERALIZADO DE BOLIVIA, Y MEMORIA EXPLICATIVA. By V. OPPENHEIM. *Bol. Soc. Geol. del Peru*, xvii, pp. 22, with coloured map. Lima, 1944.

Up to the present time there has been no geological map of the whole of Peru. The present publication, considering the small scale (the map measures 10 by 7 inches) is naturally very generalized, as the title implies. The formations coloured are Precambrian, Lower and Upper Palaeozoic, Lower and Upper Mesozoic, Kainozoic, Pre-Tertiary and Tertiary Igneous. The Republic has always been regarded as including three zones : the Coastal Region, the Sierra, and the Selva, the last named, entirely Tertiary, being in fact the headwater region of the Amazon. The Pre-Tertiary igneous rocks are mostly in the coastal region, while the rest form the Andes, with still active volcanoes. A list is given of publications on the geology of the country, other than those included in the Bulletins of the local Geological Society, which have appeared since the publication of Steinmann's great work *Geologia del Peru* in 1929.

Although the scale of the map of Bolivia is about four times as large

as the foregoing its general character is much the same. The stratigraphical divisions adopted and the colours of the map are similar, but not identical. A notable difference is that the south-east part of Bolivia is occupied by the westernmost extension of the Brazilian Shield. In Bolivia the Lower Palaeozoic includes the Devonian, while the Upper Palaeozoic is called Permo-Carboniferous. It includes tillites and is evidently of Gondwana facies. The frequency of red strata is noted and it is pointed out that Steinmann's " Red Beds " may include anything from Palaeozoic to Pliocene, and this nomenclature is therefore avoided. The structural units of Bolivia here recognized are : the Brazilian Shield ; the great syncline of the Chaco and Rio Beni, filled with Tertiary and Recent strata ; the Precordillera, strongly folded strata of various ages, with oil ; the Cordillera Real and Central, mainly Silurian and Devonian ; the Altiplano, between the Cordilleras Real and Occidental ; the Cordillera Occidental, mostly composed of basic volcanic rocks. There is a bibliography of 171 items, which does not include the mining literature.

R. H. R.

RECORDS OF THE DEPARTMENT OF MINERALOGY, CEYLON. Professional Paper No. 1. By D. N. WADIA. 4to, pp. 38, with figures. Government Press, Colombo, 1943.

This is the first publication of the newly reconstituted Department of Mineralogy of Ceylon, the successor of the old Mineral Survey. The Government has been fortunate enough to secure for some years the services of the distinguished Indian geologist, Mr. D. N. Wadia, and the three short memoirs and a bibliography, here published, represent the first-fruits of his work.

From time immemorial Ceylon has been famous as a source of gemstones which, as well as many other minerals of interest, are almost entirely worked in alluvial deposits, but were derived originally from Precambrian metamorphics. Another important economic product, graphite, occurs in the same ancient formation. The following are brief notes on the three memoirs here included.

(1) *Rare Earth Minerals in Ceylon Rocks.*—This begins with a short and interesting summary of the general geology of the island. Nine-tenths of its surface is occupied by Precambrian rocks. These include a basement of fundamental gneisses, overlain by a great thickness of metamorphosed sediments with intrusions, here correlated with the Dharwars of India, and locally known as the Khondalite, or more picturesquely as the Taprobane or Serendib System. These afford a good example of the static phase of metamorphism due to high temperature and non-directional pressure at great depths, and characterized specially by small-volume anti-stress minerals. They are largely of sedimentary origin, but three types of granite are recognized, viz. charnockites ; a white zircon-granite, and a pink granite ; some rocks of migmatitic type are difficult to distinguish from the fundamental gneisses. Practically all the rare-earth minerals originate in this system. Unfortunately space

will not here allow of a detailed discussion of them. Thorite and thorianite are well-known products of Ceylon and many others contain uranium as well as the usual "rare-earth" group. Rather oddly ilmenite is included, although as Mr. Wadia himself points out, titanium is one of the commonest elements of the whole earth. Some of the rare minerals are found in granite-pegmatites, some in the metamorphosed sediments, including limestones.

(2) *The Graphite Deposits of Ceylon.*—(The long title of this memoir is here abbreviated.) It is well known that Ceylon produces some of the best graphite of the world, much of it up to crucible standard. It is chiefly found in the metamorphic limestones in veins, joint fillings, etc. Mr. Wadia thinks it has been formed by intense metamorphism of carbonates, the lime and magnesia going to silicates and the CO_2 being reduced to carbon, which moved as liquid or gas. This seems rather a large order, with the melting point of carbon given as 3000° C.

(3) *The Three Superposed Peneplains of Ceylon.*—Geologically this is the most interesting of these memoirs. The island shows three very definite levels: a coastal plain; an intermediate one at about 2,500 feet, and a third central one with a maximum of about 8,000 feet, determined by the summits of the highest mountains. The obvious explanation, as worked out by F. D. Adams, was successive bodily uplifts of the island, but Mr. Wadia brings cogent evidence to show that this will not work. In the first place, the coastal plain, up to 400 feet, is clearly the oldest, as it carries one or two tiny patches of late Gondwanas (Jurassic) with plants, as well as some Miocene limestones, and further, to put it as shortly as possible, the denudational type of the highest scarp is the newest, not the oldest, as it should be on the bodily uplift theory, the second scarp being intermediate in type. Both the upper blocks are roughly oval in shape and more or less concentric with the whole island. The author's explanation is that they are fault-blocks: in other words, that each rose successively like a gigantic plug, the central one last. This seems to involve some very remarkable tectonics, in a sense the inverse of a cauldron subsidence; there seems, however, to be no evidence of any accompanying igneous action, at any rate at the surface.

(4) *Bibliography of the Geology of Ceylon.*—A valuable list (five pages) of the literature dealing directly with the geology and mineralogy of the island. Casual references in general literature, abstracts, and reviews, are not included.

R. H. R.

SQUIRE: MEMORIES OF CHARLES DAVIES SHERBORN. By J. R. NORMAN. 8vo, pp. 202, 10 pls. (5 portraits) and 2 text-figures. London: Harrap, 1944. Price 15*s.* net.

Biography owes much of its popularity to subtle flattery; the reader is subconsciously gratified in feeling that his perspicacity enables him to read so easily between the lines. But the author of this entertaining book, mindful of the conventional charity of biographers, set out tc speak as he found and to extenuate nothing. As a result he has not only produced a vivid portrait of an outstanding personality, but has also

given interesting glimpses of people and scenes in the background. Most of the material for the work was got together as autobiographical notes and was left by arrangement for a junior colleague to prepare for publication. The book is well worth reading as a character study and is full of miscellaneous information, as was Sherborn himself.

Only the first and last chapters are in chronological order, those intervening being devoted to Sherborn's activities in geology, bibliography, collecting, societies and clubs, and in the domestic and social sphere. Geologists will be specially interested in the account of the joint work with Rowe on the Chalk and with Upfield Green in Cornwall ; while reminiscences of such well-known men as Rupert Jones, Topley, Murchison, Henry Woodward, Lapworth, and Whitaker are very well told. There are also two less elegant stories which Sherborn specially wished to be recorded ; but had he moved in academic circles he would have known that most students hear them before they finish their second year in geology. It is rather disappointing to see these stories in print because they sounded so much better as Sherborn used to tell them, as he did whenever he thought he found an uninformed listener.

Sherborn's versatility was generally recognized, and the details given in this book show that he was an authority on Byzantine copper coins, Victorian embossed envelopes, engravings, and rare books, as well as the possessor of a choice selection of autographs, postage stamps, and Greek pottery. One item of information likely to be new to geologists is the statement that, when going through Murchison's papers, he learned that the octavo edition of *Siluria* was written for Murchison by Rupert Jones.

Bibliography was Sherborn's chief interest, and the chapter on this subject includes a detailed and valuable history of the *Index Animalium*, and is adorned with sundry personal comments, typically Sherbornian. A list of his own publications, numbering 202 items, forms an appendix at the end of the volume.

In the latter part of his life Sherborn rarely attended scientific meetings although he belonged to four of the larger societies. Among the material that he left for record are some amusing descriptions of men who contributed to the lighter side of the Geological Society's meetings in his early days ; such as the third Earl of Enniskillen, who, being deaf and with failing sight, used to hammer on the floor long after the applause had ceased ; R. W. Mylnė, whose habit of waving his arms when addressing the Fellows caused him to be known as Windmylne ; and McKenny Hughes, who " planted " a tobacco pipe (to be found at the appropriate moment) among the exhibits of his opponent Henry Hicks.

The domestic and social sides of Sherborn's life are well described, and we get an admirable picture of his home and his habits. His personal characteristics are quite frankly told, and the story of the incident at the Oxford Vice-Chancellor's lunch-table is well worth telling. Extracts from numerous letters and post cards give a fair idea of his character, but he is seen at his best in his letters to Rowe's daughter when she was a child. The over-long account of his last days is inclined to be sentimental ; but then, so was Sherborn.

C. P. C.

THE RELATIONSHIP OF THE AUSTRALIAN CONTINENT TO THE PACIFIC OCEAN —NOW AND IN THE PAST. (Clarke Memorial Lecture, 30th May, 1944.) By W. H. BRYAN. *Journal and Proceedings of the Royal Society of New South Wales*, vol. 78, pp. 42–62, map. 1944.

MOUNTAIN GROWTH, A STUDY OF THE SOUTHWESTERN PACIFIC REGION. By WILLIAM HERBERT HOBBS. *Proceedings of the American Philosophical Society*, vol. 88, No. 4, pp. 221–268, 36 maps and 41 other text-figs. 1944. (Price $1.)

According to Bryan an Australian continent, or Australasian land mass of which Australia is but a remnant, formerly extended far eastward. Though it was dismembered by very extensive submergence in early Tertiary times (no alternative hypothesis of lateral drift is considered) " the structural limit of the original Australian mass is still very clearly indicated by a well-defined seismic zone ". Westward of this mobile belt is the stable land of Australia, together with an extensive submerged area east of it. Beyond the mobile belt is the vast Pacific basin with various features that make it unique—its concordant coasts, its seismic inactivity over an enormous area, and its floor of sima.

The placing of the Pacific border in the seismic belt instead of at the coast of Australia is not a new idea ; but Bryan emphasizes its corollary, the great extent of the primitive Australian mass. He shows that the seismic zone of obvious crustal mobility occupies a belt only of moderate width and also that it closely coincides with the " andesite line " of Born and also with the " Marshall line "—the line east of which volcanoes are basaltic and (according to Marshall) the " islands are different in structure, nature, and origin " from lands to the west. These latter, which must be regarded as fragments of the greater Australia, include in the border zone New Zealand and the Kermadec, Tonga, Fiji, New Hebrides, Solomon, and Admiralty Islands. New Caledonia is well within the ancient land mass.

Bryan maintains that the thick Palaeozoic formations of eastern Australia accumulated in a geosyncline within the borders of the primitive continent. He opposes the doctrine of " marginal growth " of the Australian land eastward from a Proterozoic nucleus.

In a profusely illustrated memoir Professor Hobbs presents an admirable survey of the Asiatic-Pacific island festoons, which is the result of a study that has extended over many years and has included much original work in the field of exploration. Incidentally he restates his theory of the origin of igneous rock types by simple fusion of sediments of various kinds, and also his well-known explanation of the mechanism of compressional folding by underthrusting from a sinking sub-oceanic wedge.

He presents and discusses maps on which he has delineated the anticlinal crests and synclines manifested by island arcs and their closely-parallel trough deeps and draws attention to the arcuate festoons of active volcanoes associated with the former. He then traces the boundary in the western Pacific region between the developing arcuate folds and nascent mountain ranges of the bordering region and a vast Central Pacific basin with an entirely distinct structure—a non-folded region characterized by block faulting and subsidence. The border belt is

mobile and intensely seismic as contrasted with the central basin which is very stable (non-seismic). The volcanoes of the former are andesitic, while, on the other hand, lava domes of olivine basalt make the islands and presumably (eroded and submerged) underlie also the myriad atolls of the Central Pacific.

Analyses of rock specimens as well as characteristic geomorphic features of the Caroline Islands (Truk, Ponape, Kusaie) show that this group belongs to the central region. (One may note that the high content of FeO in the rocks from these islands suggests their close affinity with Washington's plateau basalt and with undifferentiated sima—8.85, 9.67, and 9.66 respectively.) This group lies well to the east of the great Marianne andesitic arc and its outlying parallel trough deep.

Farther south Hobbs, like Bryan, adopts as the boundary of the central basin, or Pacific Ocean proper, the Marshall line, with which Born's " andesite line " approximately coincides. Thus the Bismarck, Solomon, and New Hebrides groups, which are andesitic, are shown to be in the zone of active folding with vigorously rising anticlinal axes. (This is the chain which borders the front of the region regarded by Bryan as a foundered half of the Australian mass.)

A salient of the andesite line projects far to the north-east, enclosing the Fiji and Tonga groups. (The Fiji Islands are placed three or four degrees too far to the north-north-east on Hobbs's map, however.) When the Fijis are correctly placed it is seen that the basalt volcano Niuafo'ou and the olivine basalt domes of the Samoan Islands [1] have their place on the other side of the line and are truly oceanic.

C. A. C.

SANDS AND GRAVELS OF SCOTLAND. STONEHAVEN, PERTH, DUNDEE. By J. G. C. ANDERSON. Wartime Pamphlet No. 30. Geological Survey. pp. 32, with 5 figs. 1945. Price 1*s.* 6*d.*

In view of possible post-war needs the Scottish resources of sand and gravel are being surveyed and the results published in memoirs each covering a sheet of the quarter-inch map. The present area, Sheet 12, covers the whole of Angus, nearly all Kincardine, and parts of Aberdeenshire, Perthshire, and Fife, thus including the great city of Dundee, and several other important towns. Geologically about half is Highland and half Lowland.

Deposits of sand and gravel are very abundant, and are classified as Glacial, Freshwater, Alluvial, Marine Alluvial, and Aeolian, terms which explain themselves. It is pointed out that fluvioglacial deposits are the best of those of glacial origin, moraines often containing too much clay. There are said to be no sands suitable for good quality glass or for refractories, but a beach sand at Buddon Ness, Angus, with 73 per cent of garnet might have possibilities as an abrasive.

[1] Recently redescribed by H. T. Stearns, *Bull. Geol. Soc. Amer.*, vol. 55, pp. 1279–1332, 1944.

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Structural Features of the Grey Granites of Aberdeenshire

By James Cameron

Introduction

THE area containing the quarries discussed in this paper extends inland from the City of Aberdeen for a distance of about twenty miles and is bounded on the north and south by the rivers Don and Dee. This is the area of the Newer Granites of Aberdeenshire, which C. B. Bisset has described in " A Contribution to the Study of Some Granites near Aberdeen " and has divided the acid igneous rocks into :—

1. The Skene Complex : consisting of diorite, adamellite, grey granites, transition types and minor intrusions.
2. Later Group : consisting of coarse red granites.

The porphyritic adamellite of the Skene Complex passes northward by gradual transition into masses of more acid muscovite-biotite granite and this northern portion, forming one elongated mass stretching in a north-west direction from Aberdeen to Kemnay, is known as the Grey Granites.

At present the structure of the Grey Granites has been studied at only two quarries within the area, namely those at Kemnay and Lower Persley.

Kemnay Quarry.—This quarry lies at the northern tip of the Grey Granites within a quarter of a mile from the contact between granite and country rock. The quarry consists of two connected workings, a major one with a smaller and more recent one attached to it at the southern end. The length of the total excavation is approximately 300 yd., with a maximum width of 120 yd. and a maximum depth of 550 ft.

The shape of the quarry has been governed to a large extent by the joint planes of the rock which are large, numerous, and well-defined. The rock is a medium-grained, light silver-grey type, showing clear quartz, white felspar, and both biotite and muscovite. The biotite predominates and the cleavage flakes of this mineral have a visible parallelism in the rock. Microscopically the rock appears as an irregular aggregate of felspar, quartz, biotite, and muscovite, with accessories such as apatite, zircon, sphene, and iron ores. Orthoclase is the predominating felspar, although microcline and plagioclase are also observed. All the felspars show considerable alteration due to kaolinization. In the quartz crystals, which are generally in irregular aggregates, such features as internal sutures, mosaic

structure, undulose extinction and fluid cavities are commonly observed. The biotite crystals are markedly pleochroic with colours ranging from dark reddish brown to pale yellow and in most of the crystals pleochroic haloes are observed. Muscovite crystals although scarcer than the biotites are usually much larger. Apatite is the commonest accessory mineral.

In the quarry several thin dykes of a dark grey rock occur, intruded into joint planes of the granite. In thin section this rock is seen to be composed almost entirely of biotite and felspar, and the structure shows it to be a typical lamprophyre.

Lower Persley Quarry.—The quarry is situated on the north side of the River Don, about 4 miles from Aberdeen, and is a quarter of a mile from the granite-schist contact.

The opening is about 300 by 180 ft. across and is approximately 300 ft. deep. The four walls which are defined by joint planes, are roughly north–south and east–west. The rock is very similar to the Kemnay granite, but is slightly coarser in texture and the biotite is more abundant and in larger crystals thus imparting a slightly darker colour to the rock. The biotite crystals again show a parallelism. Microscopically the rock is extremely similar to the description given above for Kemnay granite. Bisset notes that a certain amount of variation in composition of the Grey Granites occurs and that Kemnay and Persley are probably the most acid types.

Objectives of the Investigation

Briefly stated, the objects of the work at Kemnay and Persley were as follows :—

(1) Determination of the orientation, relative importance, and ages of the joint planes.

(2) Examination of the orientation of the crystals of the various significant minerals.

(3) Study of the " ways " of the rock.

(4) Determination of the orientation of the " bubble trains " or sheets of fluid cavities in the quartz crystals.

(5) Correlation of these phenomena.

Both Kemnay and Persley quarries were studied with these ends in view, but the work at Kemnay was much more detailed than at Persley. In the following statement of results the two quarries will be treated separately ; Kemnay being dealt with first. It is intended to extend this work to cover the whole of the Grey Granites and outward into the surrounding gneisses, granites, and granodiorites. Because of the limited nature of the present investigations, generalizations will be avoided at this stage.

Kemnay Quarry

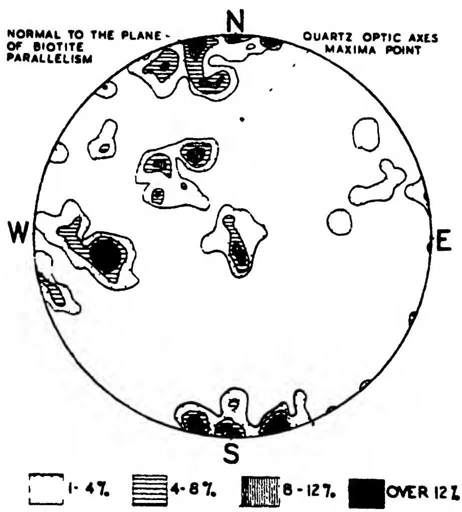
Methods of Study

The dips and strikes of over 300 joint planes were measured in the Quarry and plotted on a large-scale plan, which is lodged for reference in the Geology Department, Marischal College, Aberdeen. The normals of these joint planes were plotted on a stereographic equal area projection net, and the resulting stereogram (Text-fig. 1) shows the groups

into which they fall. Notes on the minerals associated with the joints were taken in each case.

The biotite crystals in Kemnay are lying with their cleavage faces parallel to one another and the orientation is well marked and appears constant. Measurements of the dip and strike of the plane of this parallelism were carried out in all parts of the quarry and a block diagram (Text-fig. 2) shows the geographic orientation which was found to be constant.

Three representative specimens were selected in Kemnay quarry, and their complete geographic orientation marked on them. In the laboratory



TEXT-FIG. 1.—Contour diagram of the normals to 300 Joint Planes in Kemnay Quarry.

three thin sections were cut from each specimen parallel to three planes at right angles to one another. One thin section lay in the plane of the biotite parallelism and the other two were in planes at right angles to it.

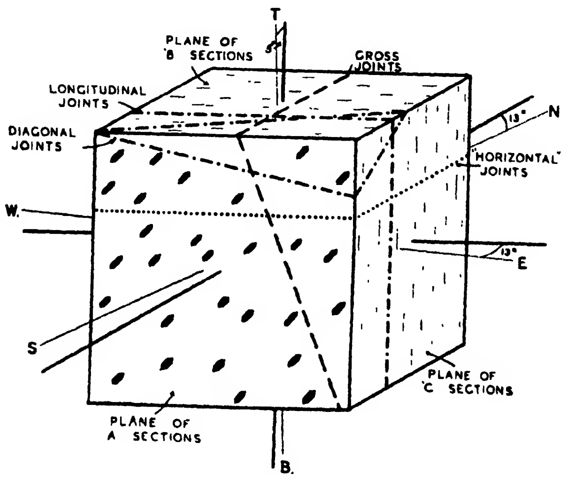
The three similarly orientated sections in the plane of the biotite parallelism are labelled the " A " sections. Each section was mounted on a universal stage petrological microscope, and the poles of the optic axes of 300 quartz crystals were determined and located on a Schmidt equal area projection net. The diagrams were counted with a 0·25 per cent counter and contours drawn at 2 per cent intervals to show areas of equal density of spacing of the poles. On each diagram the earth's great circle north–south is shown to give the geographic orientation of the section and diagram. These diagrams are shown on Text-figs. 3 and 4. All the diagrams figured are plotted on the lower hemisphere.

The acute bisectrices of the optic axes of fifty biotite crystals were determined from each section and a contour diagram made for each.

Determinations of the " rift ", " grain," and hard way or the easy,

second, and hard ways of splitting of the rock were made in the quarry, and are shown in the block diagram, Text-fig. 6.

Each thin section, with its geographic orientation marked on it was placed on the universal stage and the " strike " of at least 100 " bubble trains " or sheets of fluid cavities, which usually appear as straight lines in the quartz crystals, were measured and noted. By careful focusing and by tilting the section, the direction and the degree of dip for each sheet was also determined and noted. For each section the normals to the plane of these sheets of fluid cavities were plotted on the equal area projection net, and the result for each section is shown in Text-fig. 6.



TEXT-FIG. 2.—Block diagram showing (1) the orientation of the plane of biotite parallelism relative to the geographic axes in Kemnay Quarry. (2) A typical joint of each group. (3) The planes of the orientated thin sections.

Owing to the restricted nature of the work at this stage it is intended to deal mainly with the geometrical relations between the various phenomena, and for this reason terms with a stress reference which have been used by other writers will be largely avoided. The following terms will be used, but only with the meaning given to them here :—

Cross joints : a group of joints in the plane at right angles to the biotite parallelism.

Longitudinal joints : a group of joints lying in the plane of the biotite parallelism.

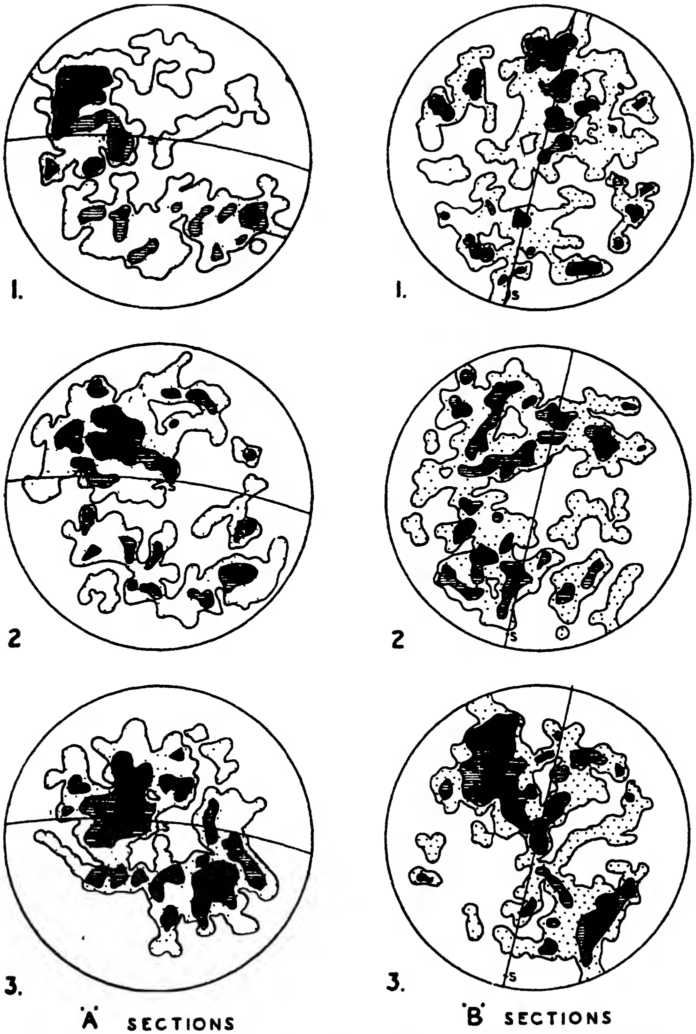
Diagonal joints : a group of joints with similar strikes and a dip of roughly 45°.

Flat-lying joints : a group of joints near the horizontal plane.

The Structural Features of Kemnay Quarry

The biotite crystals in the rock are lying with their cleavage faces parallel to one another, and this plane of parallelism is found to be

constant throughout the quarry and to have a strike of 77° east of true north, and is dipping at 85° towards the south. A block of granite broken along this plane shows the flat cleavage flakes of biotite to be elongated,



TEXT-FIG. 3.—Kemnay Quarry Petrofabric contour diagrams showing the plot on each of 300 quartz optic axes. The orientation of the sections are shown by the Earth's Great Circle N–S. Contour intervals are 1–3 per cent, 3–5 per cent, and over 5 per cent in solid black.

and this elongation has a dip of 45° towards the west. The complete orientation of the biotite crystals is shown on Text-fig. 2, and the normal to the plane of parallelism is shown on Text-fig. 1.

Joint Planes.—The ease with which the granite may be quarried is

largely governed by the joint planes in the rock, therefore the outline of the quarry is an index of the most prominent group of joint planes At Kemnay the whole quarry is elongated in a north–south direction, and the most important group of joints is found to have a north–south strike and a very steep dip.

The 300 joints whose dips and strikes were measured form over 75 per cent of all the visible significant joints in the quarry, and from these joints four distinct groups can be distinguished. These are, in order of their numerical importance : Cross joints, Longitudinal joints, Diagonal joints, and Flat-lying or Horizontal joints. The plot of the normals of all these joints on Text-fig. 1 shows the boundaries of each group. The average or typical joint from each group is also shown on Text-fig. 2. The type of mineral found in these joint planes is very characteristic of each group.

1. *Cross Joints.*—The joints in this group are the most prominent and the most numerous ones found in the quarry. From Text-fig. 1 it can be seen that the maxima area for the normals to Cross joints, which is situated at the west side of the diagram, has boundaries which indicate that the Cross joints have strikes varying from 13–5° west of true north, and a dip varying between 62–68° towards the east.

As this maxima area contains between 15–25 per cent of all the joints measured, it is the most accurate statement of the average dip and strike of the Cross joints, but the total area occupied by Cross joint normals is much larger, as indicated by the 1 per cent contour, and there are even some joints which dip in the opposite direction, but which can be most conveniently included in this group.

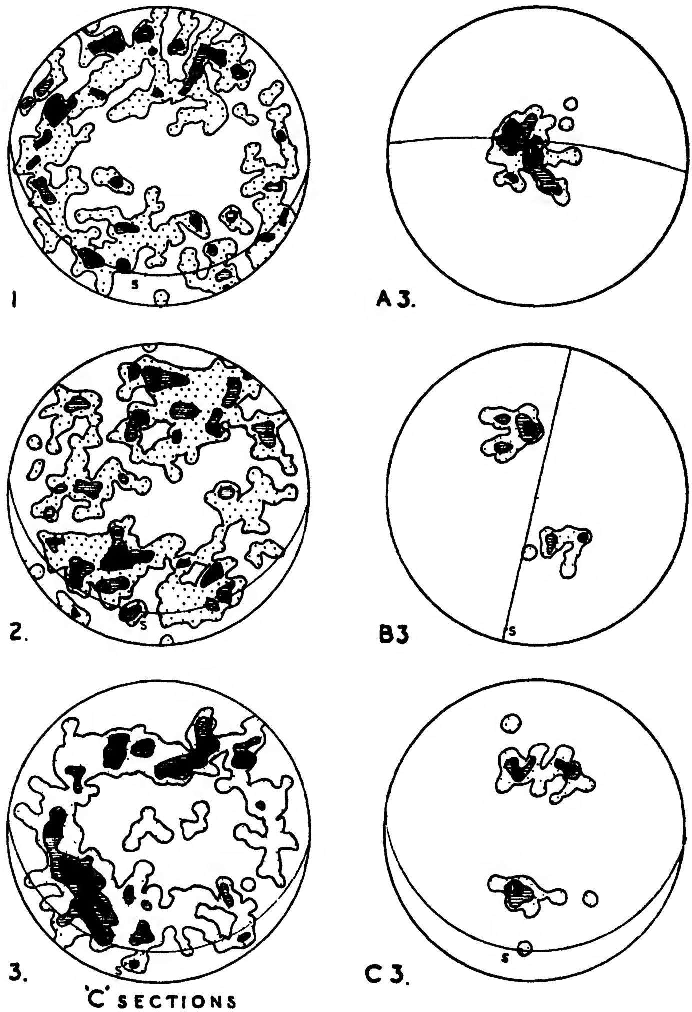
The minerals associated with the Cross joints are calcite and chlorite. Calcite veins have been found up to six inches in thickness, but usually they do not exceed half an inch. Chlorite gives a marked green colour to many Cross joints, while yellow and brown staining due to limonitization is also frequently observed. The joints are all smooth, straight, and persistent, and occur at all levels, frequently in parallel series.

2. *Longitudinal Joints.*—Although the joints in this group are numerically almost as great as the cross joints, the individual joints are less prominent.

The area of the normals to the longitudinal joints surrounds the north and south poles of Text-fig. 1, and within this area there are two maxima. One of these indicates that the longitudinal joints have a strike varying between 75–79° east of north and a dip varying between 85° north and 88° south, while the other maxima shows a strike of 99° east of north and a dip of 85° north. The longitudinal joints are less well defined than the Cross joints, but the most important maxima area shows that the average longitudinal joint is vertical and has a strike in the plane of the biotite parallelism.

The minerals associated with the longitudinal joints are barytes, fluorspar, and pyrite. Barytes, which has a pink colour, is fairly abundant, and is found covering the joints to a maximum thickness of half an inch. Fluorspar in the form of tiny yellow cubes is found encrusting the surface of a few longitudinal joints, while pyrites is found in some of the deepest longitudinal joints at present exposed. These minerals are quite characteristic of this group and are not found in any other joints.

3. *Diagonal Joints.*—The plot of the normals to the diagonal joints in Text-fig. 1 shows a fairly well defined area in the north-west quadrant, having boundaries which indicate a strike variation between 17–77° east



TEXT-FIG. 4.—The first column should be read with Text-fig. 3. It shows the contour diagrams of 300 quartz optic axes in the "C" sections. Contour intervals are the same as in Text-fig. 3. The second column shows the plot of the acute bisectrices of the optic axes of 50 biotite crystals from three sections at right angles to one another. Contours are at 10 per cent intervals with over 40 per cent in solid black.

of north and a dip varying between 20–60° to the south-east. The principal maxima lies at 65° east of north, dip 45° south-east.

These joints all show smooth fresh surfaces, and are covered by a

veneer of quartz up to a quarter of an inch in thickness, and this quartz shows indications of differential movement along these joints. In a few cases thick segregations of biotite and muscovite occur along the plane of these joints.

4. *Flat-lying Joints.*—These joints are all very nearly horizontal, and they are much more common near the surface and are comparatively rare in the deepest parts of the quarry. In Text-fig. 1 the normals occupy the centre portion of the diagram, indicating a variable strike but a consistently low dip.

These joints never have any minerals associated with them, and the surface is always rough and fresh, and they are seen to cut all the other types of joint.

The Lamprophyre Intrusions.—There are five separate dykes of dark grey intrusive rock in the quarry. The most important one, which is 5 ft. thick, has a strike of 23° west of north, and dips at 85° to the west, and although this is not a typical cross joint trend it is closer to this group than to any other. This intrusion is cut across by two parallel dykes, 6 inches and 2 feet thick, which have a strike of 12° east of north and dip 45° south. There are also two other thin dykes in the quarry having a strike of 32° east of north, dip of 35° to south-east, and these four dykes come within the boundaries of the diagonal joint group. In several places longitudinal joints with a half-inch filling of barytes are found to cut across the diagonal intrusions without interruption.

Orientation of the Quartz and Biotite Crystals

Text-figs. 3 and 4 show the quartz diagrams from nine different sections. The " A " diagrams are made from three similarly orientated sections from different specimens, each cut in the plane of the biotite parallelism. The " B " diagrams are from sections cut in the near horizontal plane at right angles to the A plane, and the " C " diagrams are from sections in the near vertical plane at right angles to the A plane.

At first sight these diagrams appear to have a completely haphazard arrangement of the fabric elements, but on closer inspection there is found to be a similar grouping of maxima areas in the A diagrams. The main maxima area is found in the same quadrant in each case, with a smaller maxima area in the diametrically opposite quadrant, and there is therefore a slight tendency for the quartz optic axes to have a preferred orientation. The B diagrams do not show such a well-marked grouping of the fabric elements, but there is a general concentration of the maxima into two areas, with the larger grouping at the upper side of the diagrams in each case. In the C diagrams there is a fairly distinct grouping of the fabric elements around the circumference of each diagram, with a characteristic area of no concentration in the centre of each.

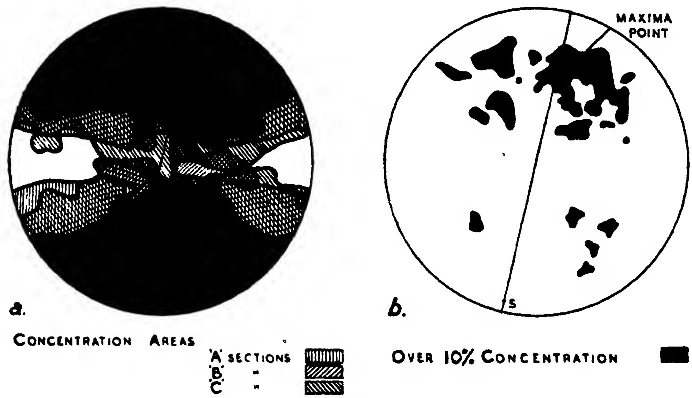
In order to clarify the common characteristics of all nine diagrams, each measured optic axes from the " A " and " C " sections was replotted relative to the plane of the B sections, thus giving nine diagrams with a similar orientation. When the areas of no concentration from each of these is superimposed on one another Text-fig. 5*a* is produced, and similarly when the maxima areas of over 10 per cent are superimposed on each other Text-fig. 5*b* is produced. Text-fig. 5*a* shows that there

are practically no quartz optic axes lying in a vertical plane striking approximately 80° east of north. This is the plane of the biotite parallelism. Text-fig. 5*b* shows that the maxima areas of over 10 per cent are chiefly concentrated in one area, and the point of highest concentration lies at 2° east of north, dipping 30° north.

There is, therefore, a slight but definite tendency for the optic axes of the quartz crystals in the rock to have a preferred orientation.

Biotite Diagrams.—The diagrams made from three different sections from one specimen are shown in the second column of Text-fig. 4, with the orientation of each marked on it.

These diagrams are typical and are in agreement with the other six, which are not shown. The high absorption and slight biaxial character of the biotites made the plotting of the acute bisectrices somewhat difficult,



TEXT-FIG. 5.—(*a*) Diagram made by re-orientating all the nine Kemnay diagrams on to one plane and superimposing them on one another to show the areas of minimum concentration. (*b*) Diagram made by a similar method to bring the maxima areas from all nine quartz diagrams on to one plane and show the maximum concentration area.

but it is quite definite that only in the " A " diagrams, i.e. in the plane of the biotite parallelism, is the concentration area to be found in the centre. In the other diagrams there are two concentration areas near the north and south poles. This evidence is therefore in agreement with the visible orientation of the biotites in the rock.

Easy, Second, and Hard Ways of the Rock

It is a well-known fact that many granite rocks possess the property of splitting more easily along one plane than along any other, and this plane, together with the two others at right angles to it, are used to produce a rectangular block in quarrying. These planes have been variously named, but although the usual terms are rift, grain, and hardway, or reed and hem, the local terms are easy way, second way, and hard way, and as these are self-descriptive they will be used here.

The easy way in some granites has been shown by T. N. Dale to be determined by minute parallel cracks and parallel sheets of fluid cavities

in the quartz crystals. Other writers have suggested that the easyway coincides with the plane of parallel phenocrysts, or with the plane of parallelism of the mica flakes in the rock. J. G. C. Anderson notes in the "Granites of Scotland," that the easy way at Kemnay is an exception to this last statement, for it is at right angles to the plane of the biotite parallelism.

At Kemnay there is a very great difference in ease of splitting between the easy way and the hard way, and this difference is as great at a depth of 500 feet as it is near the top of the quarry. On the block diagram in Text-fig. 6 these three ways are shown in relation to a block of granite. (The easy way is nearly horizontal, the second way is in the plane of the biotite parallelism, and the hard way is at right angles to these two.) Geometrically both the easy way and the hard way bear exactly the same relationship to the orientation of the biotite cleavage flakes, because both are at right angles to the plane of the parallelism and at 45° to the long axis of each biotite crystal.

In attempting to study the cause of the ways of the rock in more detail, the very tiny cracks and sheets of fluid cavities in the quartz crystals were investigated as described in an earlier section. These sheets are very numerous and well developed in the quartz crystals. Text-fig. 6 shows nine diagrams prepared from the normals to the sheets of fluid cavities in the quartz crystals.

The diagrams from the "A" sections show two concentration areas of normal points on the circumference, diametrically opposite to each other and in such positions as to indicate that the sheets of fluid cavities lie approximately in a north–south vertical plane. In the sections these sheets were seen as clearly defined straight lines of fluid cavities, varying in size, and some very fine lines can be seen to pass uninterruptedly from the quartz crystals into the adjacent felspars.

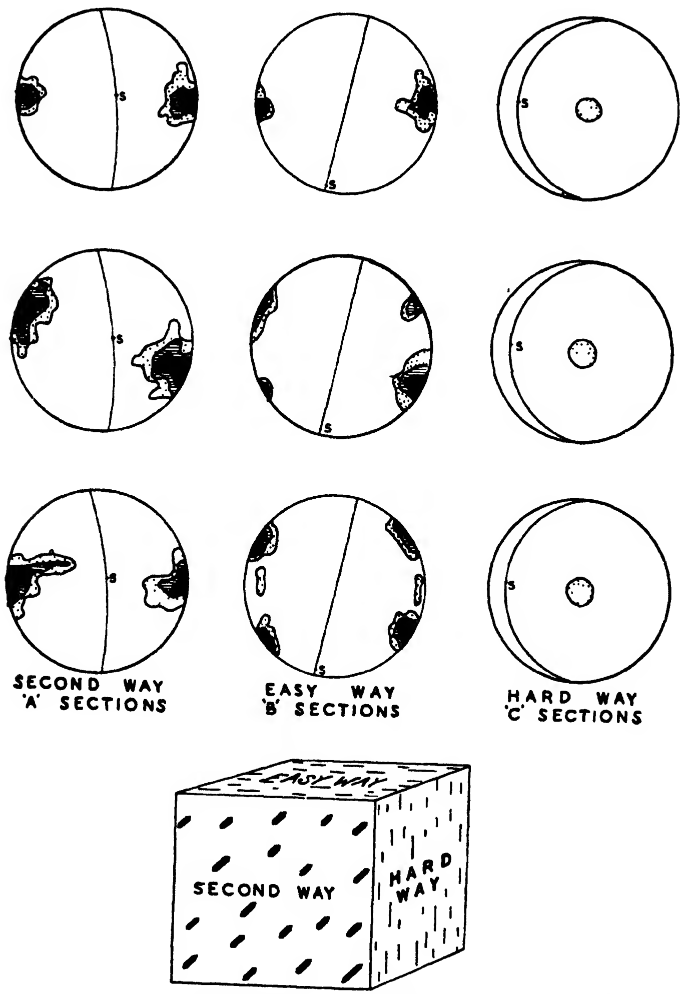
A similar concentration of normal points on the circumference was found in the B diagrams, although in two of the diagrams the concentration areas are divided, indicating that although the sheets of fluid cavities are nearly all vertical to the plane of the section the strike direction varies. The majority of the sheets do lie approximately in a north–south vertical plane.

In all three "C" sections similar phenomena could be observed, such as the random distribution of numerous bubbles over some quartz crystals, the lack of any sign of fluid cavities or cracks in others, and in some sheets of fluid cavities could be followed over the complete field of vision by merely focusing upwards through the width of the section. Thus the diagrams for the "C" sections are very different from the "A" and "B" diagrams, having only a small area of 1–3 per cent in the centre of each, indicating that the sheets of fluid cavities are parallel to the plane of the section.

The results which can be deduced from the nine diagrams are in agreement with one another and indicate that the sheets of fluid cavities are lying approximately in the north–south vertical plane. This plane is the hard way of the rock.

Neither the biotite parallelism nor the fine cracks and sheets of fluid cavities in the quartz crystals can be the means by which the rock splits

so easily along the horizontal plane, and even after careful examination no other microscopic feature was found to indicate an explanation of the easy, second, and hard ways of the rock.



TEXT-FIG. 6.—Contour diagrams of the normals to the sheets of fluid cavities in the quartz crystals, from the nine Kemnay thin sections. 100 sheets were measured where possible. Contour intervals are 1–3 per cent, 3–5 per cent, and over 5 per cent. The block diagram, similarly orientated to Text-fig. 2 shows the " ways " of the rock.

Correlation of Results

For reasons which have already been stated, the correlation of the results of these investigations will be mainly geometrical. The following

are the main points which emerge from this study of Kemnay granite. (1) There is a plane of parallelism of the cleavage flakes of biotite at 77° east of north, dip 85° south, and the long axis of each crystal is dipping towards the west at an angle of approximately 45°. (2) Four distinct groups of joint planes have been identified. The cross joints are striking at right angles to the plane of biotite parallelism and dipping at 65° towards the east, which is approximately at right angles to the secondary orientation of the biotites. The longitudinal joints lie in the plane of the biotite parallelism. (3) The characteristic mineral filling in the joints of the different groups indicate a difference in ages between these groups. The cross joints and diagonal joints are older than the longitudinal joints, and all three are older than the flat-lying joints. It is probable that the cross joints are older than the diagonal joints, but this has not been definitely proved. (4) There is a slight but definite preferred orientation of the quartz crystals in the rock. Very few optic axes of quartz crystals lie in the plane of the biotite parallelism, and there is a concentration of optic axes at 2° east of north, dipping 30° north. When this point of maximum concentration is plotted on a stereogram (Pt. X in Text-fig. 1) it is found to lie at 90° along a great circle from the maxima of the normals to the cross joints and the plot of the normals to the diagonal joints is found to be intermediate between these two points on the same great circle. (5) The easy way of splitting in the rock is along the horizontal plane, while the hard way is the vertical plane at right angles to the plane of biotite parallelism. The biotite parallelism and the sheets of fluid cavities in the quartz crystals, which have been claimed by other writers to be the cause of the easy way of splitting, have been shown to bear no relation to this phenomena at Kemnay, in fact the sheets of fluid cavities lie in the plane of the hard way. A combination of such factors as the expansion of felspars on weathering and the removal of the load of superincumbent rocks by erosion has been suggested by some writers as a cause of the flat-lying joints, and it is reasonable that these same factors also give rise to a potential horizontal plane of easy parting in the rock. While it is difficult to prove this suggestion, there are no factors at Kemnay which directly disprove it.

The geometrical relations between the various factors can be summarized as follows.

In the near vertical plane, striking 13° west of north, with certain variations in dip there lie :—

(1) Cross joints which were probably the earliest joints to develop in the rock.

(2) More quartz optic axes than in any other plane.

(3) All the sheets of fluid cavities in the quartz crystals.

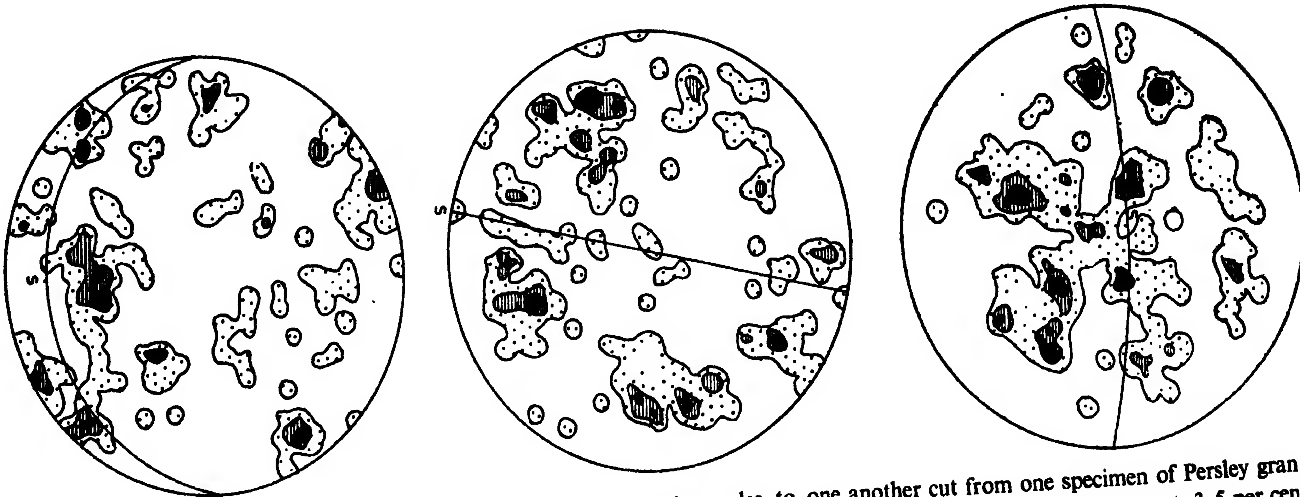
(4) The hard way of the rock.

In the plane striking 77° east of north and with a dip varying slightly on either side of vertical there lie :—

(1) Plane of biotite parallelism.

(2) Longitudinal joints which were probably the last primary joints to develop.

(3) Very few optic axes of the quartz crystals.



TEXT-FIG. 7.—Contour diagrams from three thin sections at right angles to one another cut from one specimen of Persley granite. Each diagram shows the plot of the optic axes of 200 quartz crystals. Contour intervals are 1–3 per cent, 3–5 per cent, and over 5 per cent.

Outside these two planes there are the diagonal joints and the orientation of the individual biotite crystals.

In the near horizontal plane there lie :—

(1) The flat-lying joints.

(2) Easy way of splitting of the rock.

Lower Persley Quarry

Although it was intended to carry out an exactly similar investigation of Lower Persley quarry to that already described for Kemnay, the work at this quarry had to be curtailed and therefore the results are less detailed and some parts have been omitted. The general outline of the methods of study were similar. The dips and strikes of a large number of joint planes were measured, and also the orientation of the biotite parallelism. Two orientated specimens were collected and three sections at right angles to one another were cut from each, one section being in the plane of the biotite parallelism. Petrofabric diagrams were made showing the distribution of 200 quartz optic axes from each section, and three of these diagrams, all from one specimen, are shown in Text-fig. 7. The easy way, second way, and hard way were determined in the quarry, but no microscopic determinations of the sheets of fluid cavities in the quartz crystals have been carried out.

Orientation of the Biotite Crystals

The cleavage flakes of biotite are arranged parallel to a vertical plane, but the strike of this plane varies in different parts of the quarry from 45° west of north to true north. The most persistent direction, and the one which is found to be constant over the floor of the quarry is 13° west of true north. No lengthwise orientation of the biotite crystals could be discovered.

Joint Planes

Cross joints : This group is prominent and well-defined in the quarry, having an average strike of 82° east of north and a dip which varies between 45°–85° to the south. The term " cross joints " is used because their strike is almost exactly at right angles to the plane of the biotite parallelism.

Longitudinal joints : These joints have a strike which is consistently in the plane of the biotite parallelism, and they are nearly all vertical. Many of these joints are large and well defined.

No other group of joints can be identified in the quarry, and there are only a few joints with random dip and strike which do not fall into one of these two groups. Flat-lying joints are not common.

Orientation of the Quartz Crystals

The three quartz petrofabric diagrams in Text-fig. 7 show a completely random distribution of the fabric elements, and this was also true in the three other diagrams which are not shown. No consistent maximum or minimum areas can be seen when all the diagrams are re-orientated into one plane and superimposed on one another. It must therefore be assumed that the quartz crystals in the rock have no preferred orientation.

The easy way of the rock coincides with the plane of the biotite parallelism, the second way lies in the horizontal plane, and the hard way, although vertical, has a strike which coincides with the cross joints.

Conclusions

The geometrical relations between the various items can be summarized as follows :—

In the plane, which has a strike of 82° east of north and a varying dip towards the south, there lie :—

(1) The cross joints.
(2) The hard way of the rock.

In the vertical plane at 13° west of north, that is at right angles to the plane of the cross joints, there lie :—

(1) The plane of the biotite parallelism.
(2) The longitudinal joints.
(3) The easy way of the rock.

No other important structural features are found in the quarry.

General Conclusions

Of all the features which have been described the only ones which can be geometrically related to one another and which are common to both quarries are : (1) A parallelism of the cleavage flakes of biotite. (2) A group of joints in a plane at right angles to this parallelism, and because of this termed cross joints. These vary in dip and are not vertical. (3) A group of joints lying in the plane of the biotite parallelism. (4) The hard way coincides with the plane of the cross joints in both quarries.

These four features can be compared with the structures described by many writers on the structure of igneous rocks, notably Professor H. Cloos and Dr. R. Balk, and if the biotite parallelism at Kemnay and Persley is regarded as foliation or platy flow structure then the cross joints receive the added meaning of being tension joints produced in the early stages of consolidation by the stretching of the magma along the line of the foliation. The position of the longitudinal joints relative to the cross joints and foliation is also in agreement with the many already described examples of this relationship. The mechanics of the production of longitudinal joints has not so far been very satisfactorily explained.

The petrofabric analysis has been used on the rocks from these two quarries to demonstrate that any preferred orientation of the component minerals can be found and when present it can be geometrically related to other structural features of the rock. The completely haphazard quartz diagrams from Persley and the only slightly orientated quartz diagrams from Kemnay appear to indicate that the positions which the quartz crystals occupy in the rock is unrelated to the forces which produced the biotite parallelism and the joint planes. The slight preferred orientation in the Kemnay quartz diagram does indicate that the quartz crystals did crystallize out under the influence of some extraneous force.

In the study of the ways of the rock it has been found that the " hard way " coincides with the plane of the cross joints in both quarries. In

the Kemnay rock, the sheets of fluid cavities, which have been shown by other writers to lie in the plane of the easy way, are found to lie in the plane of the hard way. It is noteworthy that these sheets of fluid cavities are numerous, well defined, and conform very markedly to the one plane.

At Persley the first way lies in the plane of the biotite parallelism and the second way is horizontal. It has also been noted that in this quarry flat-lying joints are uncommon. At Kemnay flat-lying joints are common, the first way is horizontal and the second way lies in the plane of the biotite parallelism. It may be possible that the flat-lying joints and the first way, when it is horizontal, are closely related, being different degrees of the same phenomena, and caused by the removal by erosion of the superincumbent rocks. This feature would then be local in its effect, whereas the plane of splitting which coincides with the biotite parallelism must be closely related to the forces which produced this parallelism, and probably persistent throughout the granite mass. This, however, must remain merely a suggestion, for it was not found possible to obtain any microscopic evidence to support it.

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The Micro-fabric of the Moine Schists

By F. C. Phillips

(PLATES VII AND VIII)

SOME years ago (Phillips, 1937) I published the results of a preliminary survey of the fabric of some Moine schists by the methods which have been evolved in that branch of the study of rocks now generally known as structural petrology. This survey showed that the quartz, muscovite, and biotite in all the specimens of Moine schist examined have the girdle-arrangement characteristic of a B-tectonic ; that the *b*-axes of these girdles, over a large area of outcrop, plunge in a south-easterly direction ; and that the direction of the *b*-axis of a given specimen is frequently marked by a visible lineation on the foliation-surface of the schist. Study of the fabric of Moine schists visibly affected by the dislocation-phase of the post-Cambrian movements was shown to afford support for the view, already advanced by others on the basis of petrographic study, that the ultimate effect of these movements on the Moine schists is to break down the previously existing fabric ; there is a dislocation-metamorphism " undoubtedly superposed upon the general Moine metamorphism " (Read, 1934, p. 307).

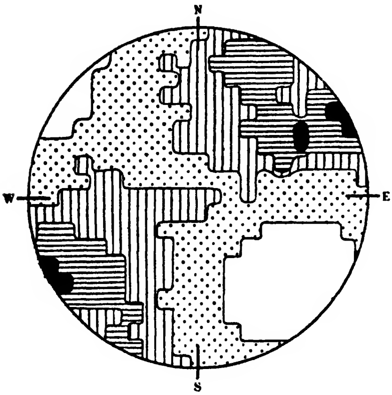
These observations were based on a comparatively limited study, though it was believed that the facts presented were sufficiently well founded not to require serious modification in the light of more detailed investigations. The present contribution examines how far this belief is justified by a greatly extended study, involving the preparation of some hundreds of diagrams of quartz, muscovite, and biotite.

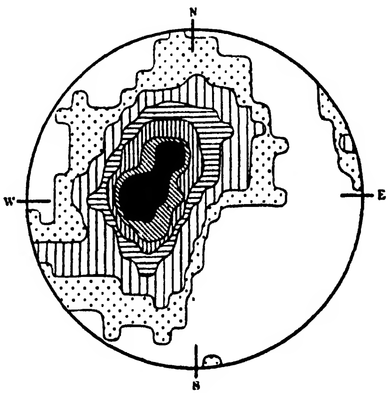
It may be stated at the outset that this extended investigation has revealed no results in marked contradiction to those of the preliminary study. The three mineral components measured show throughout a clear orientation ; in quartz there is always a characteristic girdle, very sharply defined in some specimens and less sharply so in others, but always discernible ; the mica diagrams reveal all transitions from a fairly sharply defined pole to a continuous girdle. A method of presentation of the chief results slightly different from that of the 1937 paper is therefore adopted here. Instead of a reproduction of a further selection of diagrams from individual specimens, the results have been collected to give *composite* diagrams (Ingerson, 1936, p. 172).

To test the reality of the supposed preferred orientation of quartz grains over a wide area of the Moine outcrop, 50 diagrams from widely scattered localities (selected at random, and hence derived from specimens ranging over a wide variety of strike and dip) have been rotated to their true geographical orientations, and have then been combined to give the composite diagram of Text-fig. 1. This diagram shows by the conventional contour method, on a projection of the lower hemisphere (which is used throughout this paper) the orientational distribution of the optic axes of 12,450 quartz grains. If there existed no true preferred orientation this number of measurements would surely suffice to rule out any accidents of selection and would show a uniform distribution ; moreover, a weak orientation or one present in a few specimens only would be lost in such

a composite diagram as a consequence of the wide variation of strike and dip. In actual fact the diagram shows that there is a definite tendency for the optic axes to avoid a south-easterly direction and to point preferentially north-easterly and south-westerly. There can, I think, be no doubt that a preferred orientation of the quartz-grains is a characteristic feature of the micro-fabric of the Moine schists.

Similar composite geographical diagrams have been prepared from 25 muscovite diagrams (Text-fig. 2) and from 25 biotite diagrams (Text-fig. 3), measuring normals to cleavage-planes. The evidence afforded by these is perhaps less striking than that which can be derived from a study of Text-fig. 1, for it is clear even to a casual observer that the micas in Moine schists tend to be arranged with their basal planes predominantly parallel to the foliation-surfaces. Variations of strike and dip would be





TEXT-FIG. 1.—Composite geographical diagram, 12,450 optic axes of quartz. Contours 0–½, 1, 1½, 2, 2½.

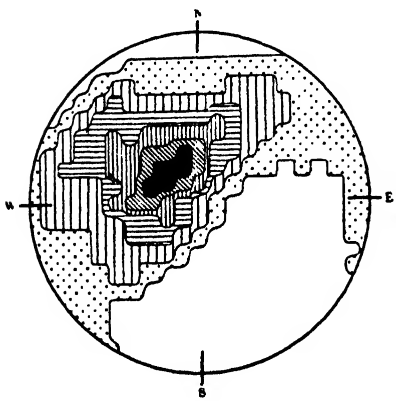
TEXT-FIG. 2.—Composite geographical diagram, 4,240 normals to cleavages of muscovite. Contours 0–½, 1, 2, 3, 4, 5, 6.

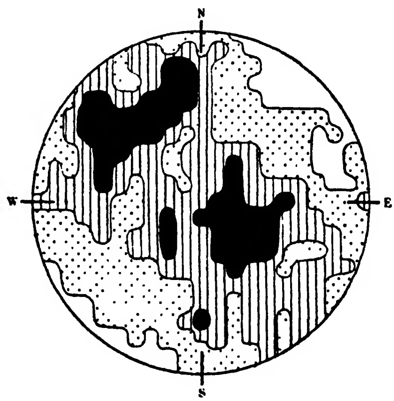
expected to give a broadened polar arrangement in a composite geographical diagram, with the pole situated to correspond to the prevalent south-easterly dip of the foliation-surfaces which is known to be characteristic of large areas of the Moine outcrop. The muscovite diagram (Text-fig. 2) shows little beyond this, but in the biotite diagram (Text-fig. 3) there is a distinct tendency towards a girdle-distribution, with the axis of the girdle plunging south-easterly in the direction which is avoided by the optic axes of quartz, Text-fig. 1.

These diagrams, it may be noted, summarize facts of observation. Any conclusions which may be derived from them are unaffected by any of the theoretical considerations of structural petrology. Text-fig. 4, for example, is a composite geographical diagram of 2,350 quartz grains from specimens of Torridonian and Cambrian sediments visibly affected by the overthrusting movements of the Caledonian orogeny. It shows that in these rocks the optic axes have no particular tendency to avoid a south-easterly direction, the unoccupied areas of the diagram lying instead in

the north-east and south-west quadrants. It would appear to be a reasonable suggestion that this contrast of preferred orientation makes it probable that the orientated quartz-fabric of the Moine schists (and therefore, presumably, the similarly orientated mica fabrics) was not built up during the overthrust-phase of the Caledonian orogeny.

Such composite geographical diagrams are not, strictly speaking, *fabric* diagrams, since the grouping of the individual diagrams into a common geographical orientation takes no account of the orientation of the reference-axes of each specimen. If, however, we are prepared to accept the conclusion that the macroscopic lineation, normal to the plane of the girdle of each diagram, is an important fabric direction, we can group a number of diagrams with their planes of visible fissility and their directions of lineation coincident throughout, and thus construct true





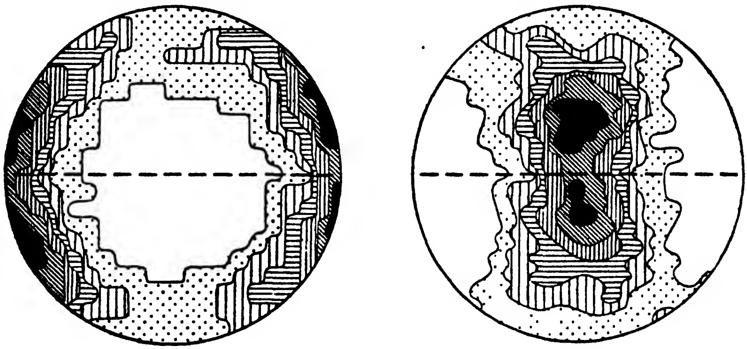
TEXT-FIG. 3.—Composite geographical diagram, 4,500 normals to cleavages of biotite. Contours 0–½, 1, 2, 3, 4, 5.

TEXT-FIG. 4.—Composite geographical diagram, sheared Torridonian and Cambrian, 2,350 quartz. Contours 0–½, 1, 1½.

composite fabric diagrams. I hope later to publish detailed descriptions of some of the types of lineation found in the rocks of the Scottish Highlands. Meanwhile, it may help the reader who is not fully versed in the findings of structural petrology to explain that the lineation referred to here is an intimate feature of the fabric of the rock, mainly determined in Moine schists by the elongation of the micas (see Plate VII, figs. 1 and 2). Numerous analyses have demonstrated that this lineation is parallel to the axis of the prominent girdle of a typical Moine diagram ; such a lineation is called *Striemung* in German literature. It is not necessarily accompanied by any visible puckering, though it may be so accompanied. Conversely, a visible puckering such as is seen, for example, in many micaceous Dalradian schists, is not necessarily a true *Striemung* ; ultimately, only a microscopic analysis can determine the true significance of a visible lineation.

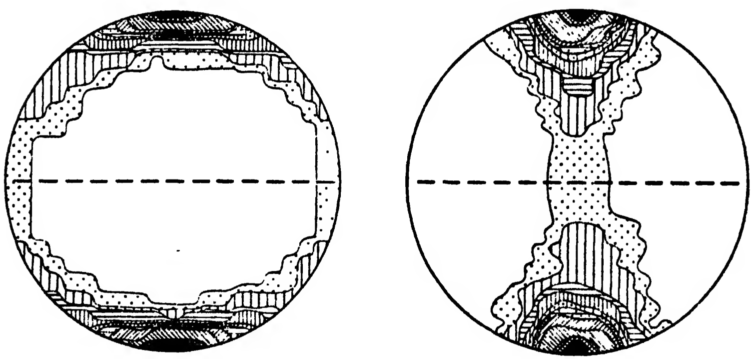
Text-fig. 5 presents composite fabric diagrams of 6,000 quartz grains from 25 specimens of Moine schist showing a well-marked lineation. The

foliation surface in these (and similar succeeding) figures is set left and right normal to the plane of the diagram ; in Text-fig. *5a* the lineation in this surface is normal to the plane of the diagram, whilst Text-fig. *5b* is the diagram of Text-fig. *5a* rotated through ninety degrees, so that the lineation lies in the plane of the diagram. The features specially to be noted are the clearly defined girdle and the pair of maxima set on either side of the foliation surface. Text-fig. 6 shows similar diagrams for



5a *5b*

TEXT-FIG. 5.—Composite fabric diagrams, 6,000 quartz. Contours 0–½, 1, 1½, 2, 2½, 3.



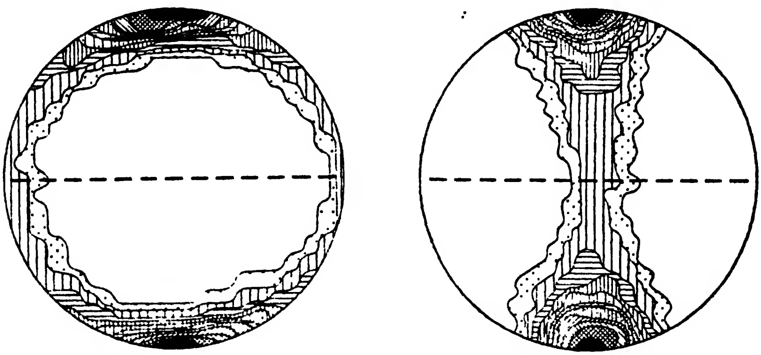
6a *6b*

TEXT-FIG. 6.—Composite fabric diagrams, 4,650 muscovite. Contours 0–½, 1, 2, 3, 4, 5, 6, 7, 9, 11.

4,650 muscovite flakes, and Text-fig. 7 diagrams for 5,000 biotite flakes. The diagrams for the two kinds of mica resemble each other closely, with a marked maximum in each indicating the orientation of a majority of flakes parallel to the visible foliation and with a continuous girdle normal to the lineation. In the muscovite diagram only the half per cent area forms a complete girdle, whilst in the biotite diagram there is a continuous girdle of one per cent. This feature of the composite diagrams is frequently noticeable in diagrams for muscovite and biotite derived from measure-

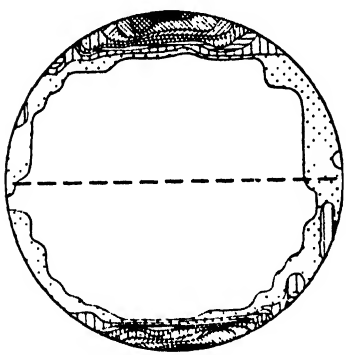
ments on a single section (see, for example, Text-figs. 8 and 9), the biotite tending on the whole to form better girdles than the muscovite, as was suggested already by consideration of the composite geographical diagrams.

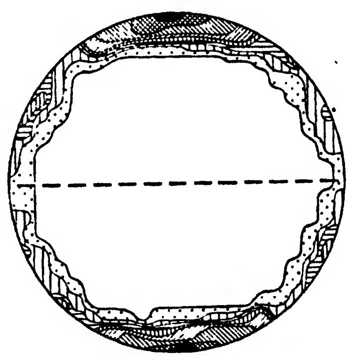
The girdle arrangement of the quartz, muscovite, and biotite, and the lineation parallel to the *b*-axis of the girdle are features characteristic



7a *7b*

TEXT-FIG. 7.—Composite fabric diagrams, 5,000 biotite. Contours as in Text-fig. 6.





8 9

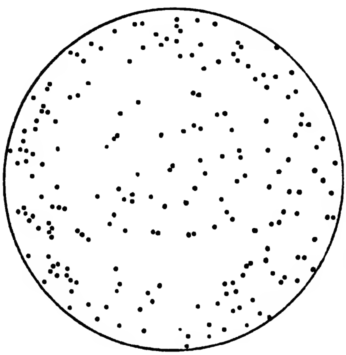
TEXT-FIG. 8.—Moine schist, 1 mile south-west of Carn Sonraichte, 300 muscovite. Contours 0–1, 2, 3, 4, 6, 9, 15, 20, 22.

TEXT-FIG. 9.—300 biotite in same slide as Text-fig. 8.

of the fabric of a B-tectonite. Two other features frequently observed in such tectonites, however, are absent from typical Moine schists. Unlike the micas, quartz does not usually show any very pronounced elongation (see fig. 3, Plate VII) and *ac* cracks are rarely seen when sections parallel to *b* are examined. The absence of these features is, I believe, to be accounted for as a result of overprinting by a later movement, as described below.

Three further points concerning this B-tectonite fabric, tentatively established by the preliminary study, may now be further examined.

1. *It is the earliest deformation-fabric imprinted upon the sediments constituting the Moine schists.* Around the Carn Chuinneag-Inchbae intrusion the original unmetamorphosed sediments have in places been preserved by conversion to hornfels from the effects of later regional metamorphism. Quartz in the hornfels itself yields, as is to be expected, disordered grain-orientation diagrams (e.g. Text-fig. 10). One of the earliest symptoms of dynamic alteration is the development of white mica (Mem. Sheet 93, p. 108), and this can be observed very close to the igneous rock itself, for the unsheared hornfels is usually separated from the igneous rock by a narrow sheared zone. These mica flakes soon become sufficiently large to be measurable and Text-fig. 11 records measurements made upon a garnetiferous quartz-felspar rock with muscovite and green-brown biotite from south-west of Carn Sonraichte.



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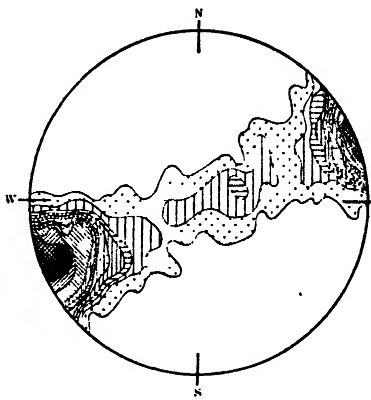

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TEXT-FIG. 10.—Hornfels, ½ mile south-east of Garbhan Mor. 200 quartz.
TEXT-FIG. 11.—Moine sediment almost in contact with igneous rock, ¾ mile south-west of Carn Sonraichte. 250 white mica. Contours 0–1, 2, 3, 4, 5, 6, 7, 8, 9, 14, 16.

The early-developing white mica is arranged in a well-defined girdle, with its axis lying south-south-east, almost horizontal. Passing over the zone of hornfels, Moine schists of normal aspect soon appear; a measured example from the head of Loch Morie, less than one mile from the outcrop of the granite, gave the usual type of quartz girdle with a *b*-axis plunging 45° slightly east of south.

As already described (Phillips, 1937, p. 595), the igneous rock itself, where it has yielded to deformation, has been converted to a B-tectonite with south-easterly plunging axis. A lineation in this direction is a prominent feature of the igneous rocks and of the schists alike in this area. Impartial evidence is provided by the Memoir on Sheet 93 and by the one-inch colour-printed map. The descriptions refer to the lineation in various terms, such as a linear foliation, as a direction of stretching or as rodding. " In the Carn Chuinneag mass the general dip, both of rods and foliation planes, appears to be south-east, at high angles " (p. 55).

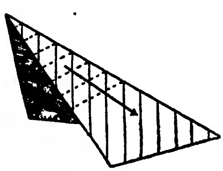
[In the schists] " a quarter of a mile south-east of Creag na Ceapaich the stretching is N.N.W.–S.S.E., nearly parallel to the dip of the foliation " (p. 27). " In Garbh Allt . . . the direction of the stretching lines is N.N.W.–S.S.E." (p. 36). In the north-west quarter of the map this " direction of stretching " is indicated at ten separate localities by a special symbol, which is marked also in the gneiss itself near Inchbae Lodge. Other features of the fabric frequently found in association with this type of lineation are accurately described. The garnets in a garnetiferous mica schist " were evidently in existence before the schist-making movements ceased, being often bordered at two opposite sides by ' tails ' of quartz. In the area, between a mile and a mile and a half south-west of Loch a' Choire Mhoir, these tails strike nearly south-east . . ." (p. 33). " South-west of the summit of Cnoc na Tuppat the garnets are distinctly elongated in one direction . . . much the same as that of the elongation of the clastic grains in the siliceous schists three-quarters of a mile south-west of the hill-top " (p. 86).

2. *The fabric was in existence before the isoclinal folding was impressed upon the schists.*—The relationship of the lineation to the axes and limbs of the isoclinal folding which is prevalent in many areas of Moine schists is more easily demonstrated in the field than by written description. Since the lineation lies predominantly in an approximately N.W.–S.E. direction, whilst the axes of the isoclinal folds usually run almost at right angles to this direction, the effect of folding subsequent to the development of the lineation would be in general to change the angle of plunge of the lineation on the middle limbs without throwing the direction of plunge out of the south-east quadrant. It is possible, however, to find areas where the lineation is oblique to the axes of folding ; a typical instance may be described from the folding by the bridge over the Blackwater at Little Garve, four miles south of Inchbae, near the locality figured by Peach and Horne (1930, pl. xv). On an upper limb dipping 27° in a direction E 22½° S. a lineation is visible pitching in a southerly direction at an angle of 63° from the dip. Measurements of the quartz, of the muscovite and of the biotite prove that this lineation is a true *Striemung*, normal to well-marked girdles. On the middle limb, which dips 58° due south, a similar lineation can be seen, and measurements of the quartz and of the micas show a precisely similar relationship between grain fabric and lineation to that of the upper limb. If the lineation was in existence before the folding occurred, and the fold was impressed with geometrical exactitude, a simple stereographic construction shows that on the middle limb the lineation would plunge at an angle of 30° in a direction W. 21° S., making an angle of pitch of 54° with the dip of the limb. The lineation actually measured in the field plunges 38° in a direction W. 29° S., pitching 44° from the dip. By cutting further sections from near the crest of the fold it has been possible to follow the lineation as it turns over from the upper to the middle limb, and it seems difficult to avoid the conclusion that the lineation, and therefore the B-tectonite fabric which it expresses, were in existence before the isoclinal folding was overprinted (Text-figs. 12, 13).

The obliquity of the lineation to the axes of the isoclinal folding also suggests in itself a lack of genetic relationship between these two features, for the normal attitude of a true *Striemung* is parallel to the axes of the

folds with which it is genetically associated. If we resort again to the Memoir on the Carn Chuinneag area, there are not wanting indications of folding with this relationship. " The strike of the beds in the largest area of well-preserved hornfels lies at right angles to the strike of the regional movements " (p. 80). " In the north-eastern part of the [Strath Vaich] district the dip changes from east to south and then to south-west as we advance north-easterly " (p. 27). " Near the foot of Alladale River [the dip is] south-west at a steep angle " (p. 31). In the gneiss, a foliation " along which the long axes of the augen lie " is in places over-printed by a second or strain slip foliation. " It is believed that the first or main foliation was produced after consolidation, and that it can be matched with a foliation produced contemporaneously in the Moine sediments " (p. 55).

3. *The fabric is ultimately broken down and obliterated when the schists*



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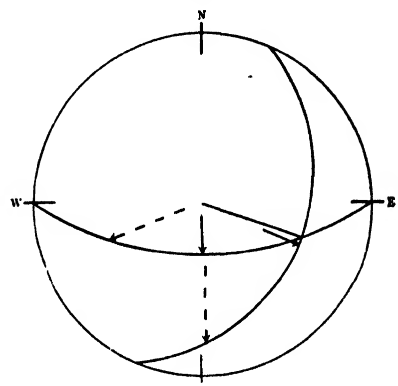

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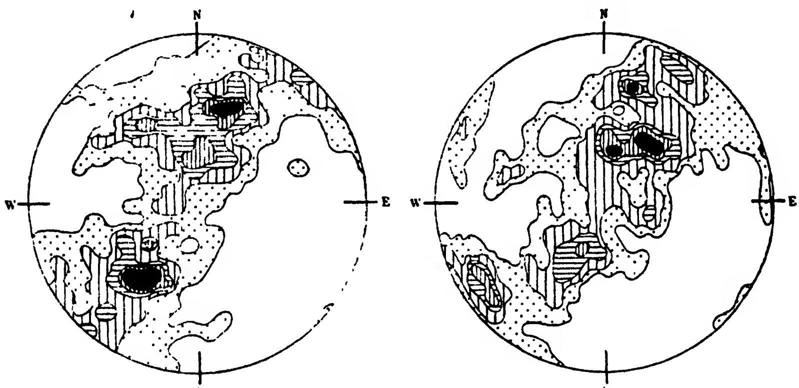
TEXT-FIG. 12.—Lineation on pitching isoclinal fold.
TEXT-FIG. 13.—Stereographic projection of the fold, Text-fig. 12. The full arrows show the dip and the broken arrows the lineation.

become involved in the dislocation-metamorphism associated with the Caledonian orogeny. This feature has now been studied in seven separate traverses at intervals along the length of the outcrop of the Moine Thrust. With the onset of the dislocation-metamorphism as one approaches the thrust, the normal girdle fabric is at first little affected ; well-defined girdles result from measurement of rocks which have been subjected to fairly considerable crushing. There is certainly no tendency, however, to the production of a *more* highly orientated fabric ; ultimately the reverse effect is seen, the fabric of the B-tectonite " falling to pieces " (cf. Schmidt, 1932, p. 198) as the effects of the dislocation-metamorphism become more marked. This is clearly seen if partial diagrams are constructed (Ingerson, 1936, p. 172 ; Fellows, 1945, p. 653) based on selective measurements made on a single section. Selective diagrams of larger relict grains and of smaller recrystallized grains, in every instance so far examined, show concordant girdles, but the girdle of recrystallized grains is in comparison less well defined.

In making measurements on partially crushed rocks of this type it is, of course, important to confirm that the homogeneity of fabric which characterizes the un-crushed tectonite is not destroyed at least during the earlier stages of crushing and recrystallization. The simplest test of homogeneity, and of the real significance of the diagrams constructed, is made by comparing the results of measurements on sections with varying relationship to the fabric. Text-fig. 14 illustrates the degree of resemblance afforded by such comparisons. From a specimen of muscovite-quartz schist quite profoundly affected by the dislocation-metamorphism two sections were cut, one normal to the strike of the foliation and the other normal to the dip. The fabric diagrams for 200 quartz grains in each were subsequently rotated to their common geographical orientation, and it will be observed that even in a thoroughly crushed rock of this kind the two sets of measurements afford essentially identical diagrams.

The fine-grained mylonites found in immediate association with the



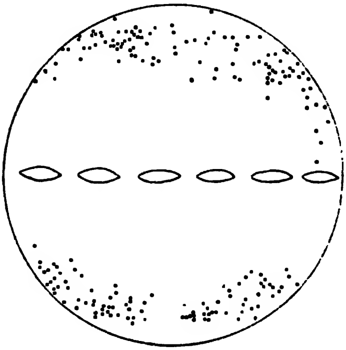
14*a* 14*b*

TEXT-FIG. 14.—Moine schist from zone of dislocation-metamorphism, Kyle Rhea, Glenelg. 200 quartz. Contours 0–1, 2, 3, 4, 5. (*a*) Section normal to dip ; (*b*) section normal to strike.

thrusts are not susceptible to optical investigation, unless some relict grains survive. In a crushed quartzose rock from the north end of Loch Hope, mapped as " Moine μ ", lenticular grains of highly strained quartz lie in a fine-grained mylonitic matrix. These lenticular grains show a concentration of optic axes nearly normal to the schistosity (Text-fig. 15). If it can be reasonably supposed that the original rock showed the normal type of girdle, this mylonite presents an interesting example of the differential yield of quartz grains to the shearing according to the attitude of their internal structure in relation to the impressed shear planes.

It may be noted in passing that the destruction of an earlier fabric by later movements can be observed in some places where Lewisian gneisses are traversed by pre-Torridonian shear-zones. Horne and Teall (1907, p. 598) have contrasted the conversion of the granular gneisses along these zones to granulites, without the development of cataclastic structures, with the conversion of similar rocks to mylonites along the post-Cambrian

thrusts with marked evidence of mechanical fracture. They suggested that the granulitic type is characteristic of plastic deformation in the "zone of flow" whilst the mylonitic type is found in the "zone of fracture". In spite of this evident difference of texture, however, it would appear, so far as my investigations of these shear-zones have been carried at present, that the pre-Torridonian shearing has often sufficed only to



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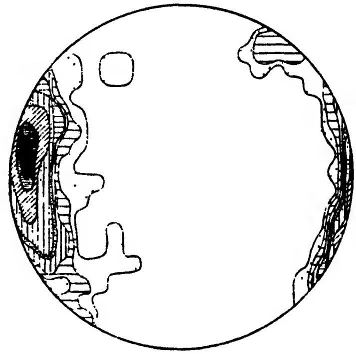

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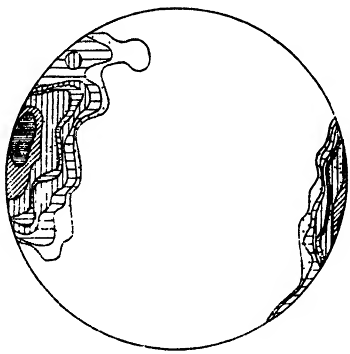

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TEXT-FIG. 15.—Sheared psammitic Moine schist, north end of Loch Hope. 200 residual quartz.

TEXT-FIG. 16.—Quartz vein in Moine schist, 3 miles south-west of Achnasheen. 250 quartz. Contours 0–1, 2, 3, 4, 5, 10, 15, 20.

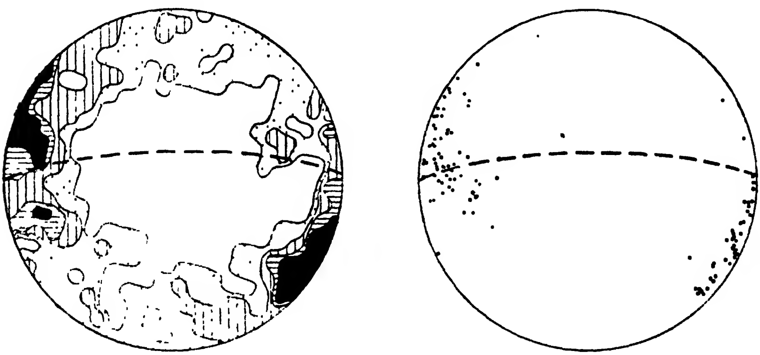
TEXT-FIG. 17.—Quartz vein in Moine schist from zone of dislocation-metamorphism, south of Attadale River, Loch Carron. 250 quartz. Contours as in Text-fig. 16.

obliterate an earlier fabric without being carried far enough to build up a new preferred orientation.

The effects of the dislocation-metamorphism may be studied also in quartz-veins and pegmatites which are found in places in the Moine schists. These intrusions are of various ages, but some are earlier than the dislocation-metamorphism and near the outcrop of the Moine Thrust are affected by it. Near Achnasheen, for example, concordant quartz-veins with small amounts of felspar have an average grain size of about 1·5 mm.

(Plate VIII, fig. 1) and show a well-marked fabric with the quartz axes concentrated in an incomplete girdle attaining a maximum of 20 per cent (Text-fig. 16). Sixteen miles to the south-west, south of the Attadale River, similar veins are found in schists strongly affected by the superposed dislocation metamorphism. The quartz of these veins has been crushed and recrystallized, the average grain-size being about 0·2 mm. (Plate VIII, fig. 2), but there still remains a high degree of preferred orientation (Text-fig. 17) with a maximum concentration only a little less than that of the uncrushed veins. There seems little doubt that when thoroughly mylonized the material of these veins, like that of the schists themselves, would become disorientated, but the survival of the earlier fabric through a considerable amount of recrystallization is in accord with the survival of the girdle of a Moine schist in a partially crushed rock, as described above.

These early quartz veins have been usually accepted as metamorphic



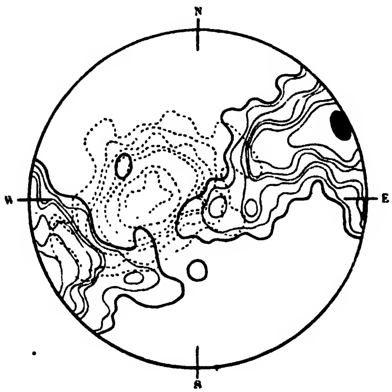
18*a* 18*b*

TEXT-FIG. 18.—Moine schist 3 miles south-west of Achnasheen. (*a*) 250 quartz in schist. (*b*) 100 quartz in a vein in the same slide.

segregations contemporaneous with the regional metamorphism of the schists (e.g. J. Horne, 1935, p. 55 ; L. W. Hinxman, 1913, p. 76), and the concordance of the fabric of the veins with that of the schists (Text-fig. 18) lends support to this view. The only alternative hypothesis would seem to be that advanced by Laemmlein (1939) in the case of quartz veins in schists in the Urals, where he suggests that a previously existing preferred orientation of the quartz in the schists has controlled the later growth of quartz in the veins. If the contemporaneity be established, it becomes an interesting field for further investigation whether a fabric of this kind exists in any of the component members of the injection complexes which were considered by some earlier observers and more recently by Read (1931, p. 12) to have been formed contemporaneously with the general Moine metamorphism.

Two further features which emerge from a detailed study of the large number of diagrams now available may be referred to in conclusion. I have described the mica and quartz diagrams as "constantly homotactic" (Phillips, 1937, p. 599), the different minerals showing the same symmetry

of arrangement. To the extent that no real conflict between the evidence afforded by quartz and that afforded by the micas has been observed, the axis of a defined mica girdle always corresponding to a direction of minimum density of occupation by quartz optic axes, this statement is abundantly confirmed by later work. Study of geographically-orientated diagrams, however, shows that there is frequently a slight discordance



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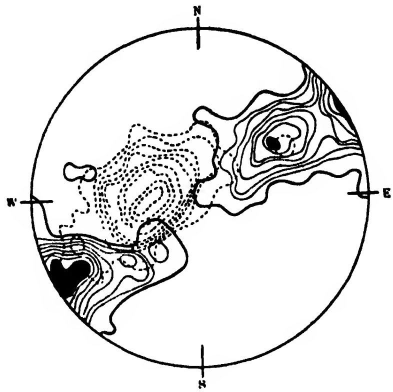

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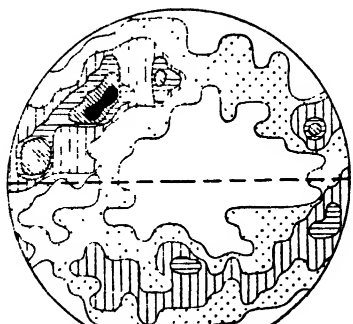

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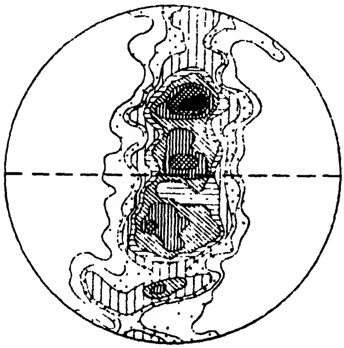
TEXT-FIG. 19.—Moine schist, north side of Loch Sgamhain, Glen Carron. Diagram for 250 biotite (dotted contours) superposed on the diagram for 250 quartz.

TEXT-FIG. 20.—Moine schist. Glencarron Lodge. Diagram for 250 muscovite superposed on the diagram for 200 quartz.

TEXT-FIG. 21.—Moine schist, Armadale Bay, Sleat, I. of Skye. 300 quartz. Contours 0–1, 2, 3, 4, 5.

between the attitudes of the mica girdles on the one hand and of the quartz girdle on the other in diagrams for the same section. Text-figs. 19 and 20, chosen as typical examples, show how the maxima of the mica diagram may not lie precisely on the quartz girdle, the effect being as if the latter had been rotated slightly about a N.E.–S.W. axis. Such a displacement

might reasonably be ascribed to the S.E.–N.W. overthrust movements, and to this same over-printing I believe should be referred also the lack of notable elongation of the quartz and possibly also the absence of *ac* cracks referred to above. These movements, which found the fabric already in existence, had little effect on the micas except in the belt of actual dislocation-metamorphism, but they have recrystallized the quartz with



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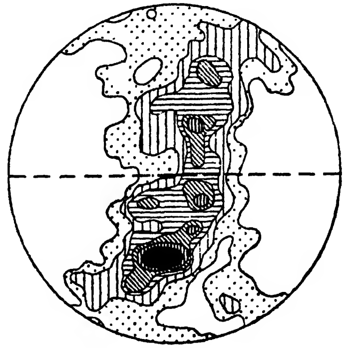

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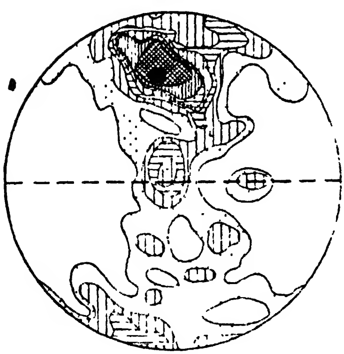

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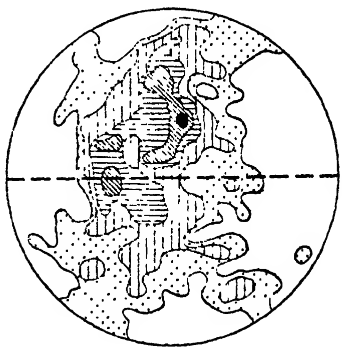

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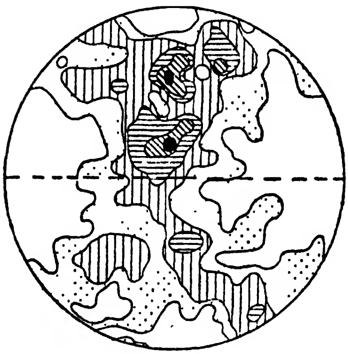
TEXT-FIG. 22.—Moine schist, Loch More, 1 mile north of Kinloch. 167 quartz. Contours 0–1, 2, 3, 4, 5, 6, 8. Diagram rotated parallel to *b*.
TEXT-FIG. 23.—Moine schist, south-east of Adag Mhor, Durness. 300 quartz. Contours 0–1, 2, 3, 4, 5, 6. Diagram rotated parallel to *b*.
TEXT-FIG. 24.—Moine schist, Glen Docherty. 250 quartz. Contours 0–1, 2, 3, 4, 5, 6, 8, 10. Diagram rotated parallel to *b*.
TEXT-FIG. 25.—Moine schist, Merkland River, 1 mile south of Merkland Lodge. 250 quartz. Contours 0–1, 2, 3, 4, 5. Diagram rotated parallel to *b*.

loss of elongation, healing of any previously existing cracks, slight displacement of the fabric, and little loss of preferred orientation.

A second, and possibly closely related, feature of the fabric, the occasional formation of a partial *bc* girdle, was briefly noticed in my earlier description (Phillips, 1937, p. 600). When quartz diagrams from a wide selection of Moine schists are reviewed they are found to show all

gradations from a simple girdle to a more complex type of diagram. In a diagram normal to the lineation, corresponding to the attitude of section usually most convenient to measure, it is sometimes seen that in place of the simple girdle around the " rim " of the projection the most densely occupied areas lie along two great circular arcs inclined downwards symmetrically below the plane of the projection (Text-fig. 21). The details of such diagrams are most easily studied in projections parallel to *b*, and Text-figures 22 to 27 are drawn in this orientation. In Text-fig. 22 the girdle is simple. In Text-fig. 23 there is some extension in the *bc* plane, the plane of projection. Succeeding text-figures show different degrees of this extension ; ultimately an empty area appears around the pole of the schistosity, and Text-fig. 27 has the appearance of a typical " crossed-girdle " diagram. This kind of two-girdle diagram has been described by several observers and has been the subject of considerable discussion (see, for example, Sahama, 1936, p. 60). Some petrologists have accepted it as



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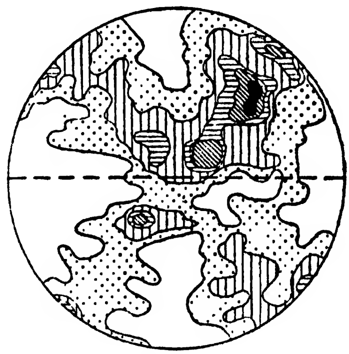

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TEXT-FIG. 26.—Moine schist, 3 miles south-east of Kinlochewe. 300 quartz. Contours 0–1, 2, 3, 4, 5. Diagram rotated parallel to *b*.
TEXT-FIG. 27.—Diagram of Text-figure 21 rotated parallel to *b*.

representing a special type of fabric diagram, and have ascribed the orientation to some particular feature of a single causative deformation, whilst others have considered that the orientation in a double-girdle diagram has been brought about by two successive non-parallel movements, the effects of a later movement being over-printed on the fabric of the earlier movement without completely obliterating it. The transitional types found in the Moine schists may perhaps be tentatively regarded as evidence for considering that the more complex diagrams here represent over-printing on a previously existing simple B-tectonite fabric during the Caledonian overthrusting.

The response of an existing orientated fabric to a later deformation has been briefly discussed by various authors (e.g. Schmidt, 1932, p, 196 ; Eskola, 1939, p. 295), and it is generally agreed that the presence of a marked preferred orientation may profoundly affect the course of subsequent events. There is some divergence of views, however, concerning

the degree of subsequent metamorphism which may be necessary to obliterate an earlier fabric. Thus, Sahama writes (1936, p. 61) : " Es ist wohl eine allgemeine Beobachtung, dass der Quarz in vielen Gesteinen durch relativ geringe Beanspruchungen sehr leicht einer Umregelung und Umkristallisation anheimfallen kann." Eskola, on the other hand, emphasizes the persistence of an earlier fabric (1939, p. 295) : " Obwohl Entregelung bei hochmetamorphen Gesteinen, besonders solchen, deren Metamorphose bis zur Grenze der Granitisation gelangte, zweifellos eine sehr häufige Erscheinung ist, könnte man sich andererseits darüber wundern, dass sie nicht noch häufiger ist. Eine Erklärung dafür ist wohl in dem Umstand zu suchen, dass die einmal durch Regelung erworbene Anisotropie eines Gesteinskörpers sehr lange und beharrlich die Richtungen der wirkenden Druckkomponenten mitbestimmt." From my own experience, mainly of the rocks of the Scottish Highlands, I would draw a careful distinction between the readiness with which quartz suffers *recrystallization* and the reluctance which it shows to undergo *reorientation.*

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EXPLANATION OF PLATES

Plate VII

Textures of Moine schists. The sections are all cut at right-angles to the foliation ; in each figure the upper strip is from a section normal to *b* and the lower from a section parallel to *b*.

Fig. 1.—Ordinary light, × 20. A semi-pelitic type, showing elongation of the biotite parallel to *b*. By the bridge over the river Mudale at the west end of Loch Naver, Sutherland.

Fig. 2.—Ordinary light, × 20. A pelitic type, with abundant mica and epidote. Both muscovite and biotite show pronounced elongation. Shore south-east of Armadale Pier, Sleat, I. of Skye.

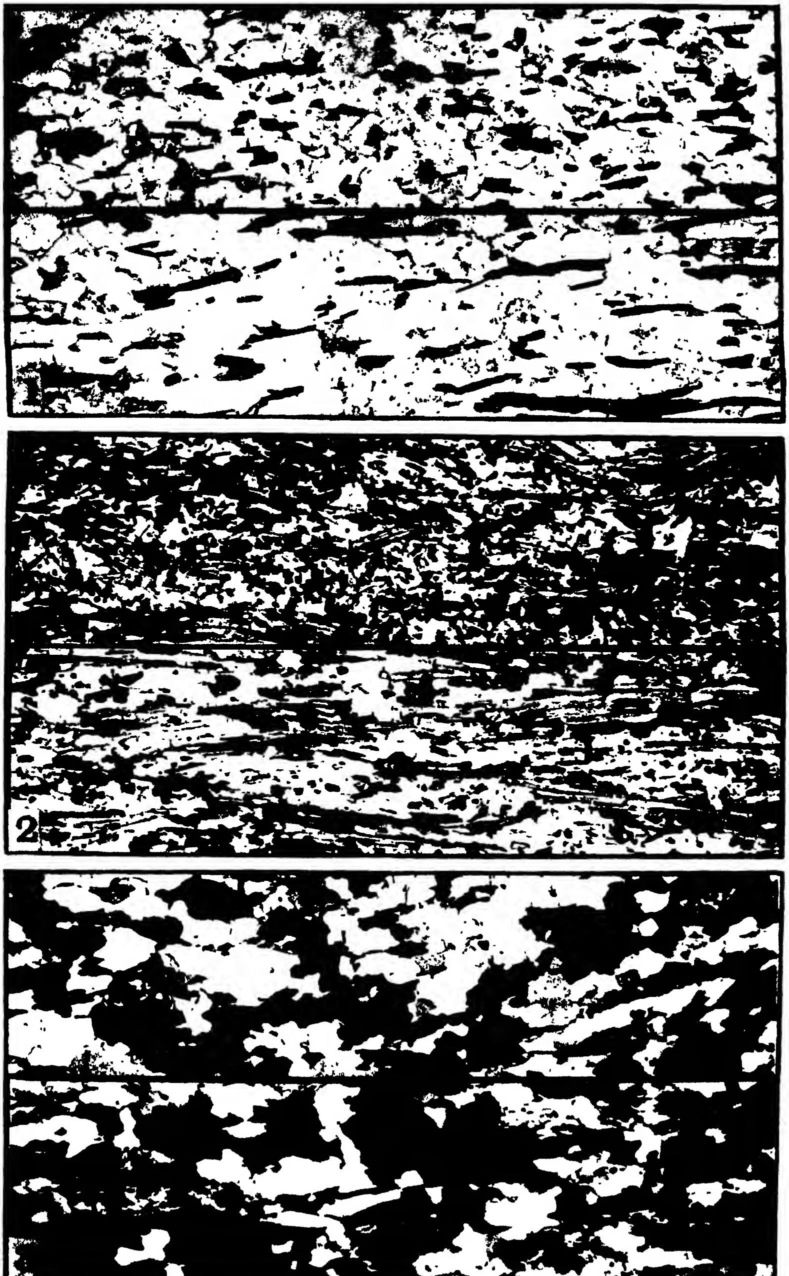
Fig. 3.—Crossed nicols, × 20. There is no marked elongation of the quartz grains. Burn on north side of Loch Sgamhain, Glen Carron, Ross-shire.

Plate VIII

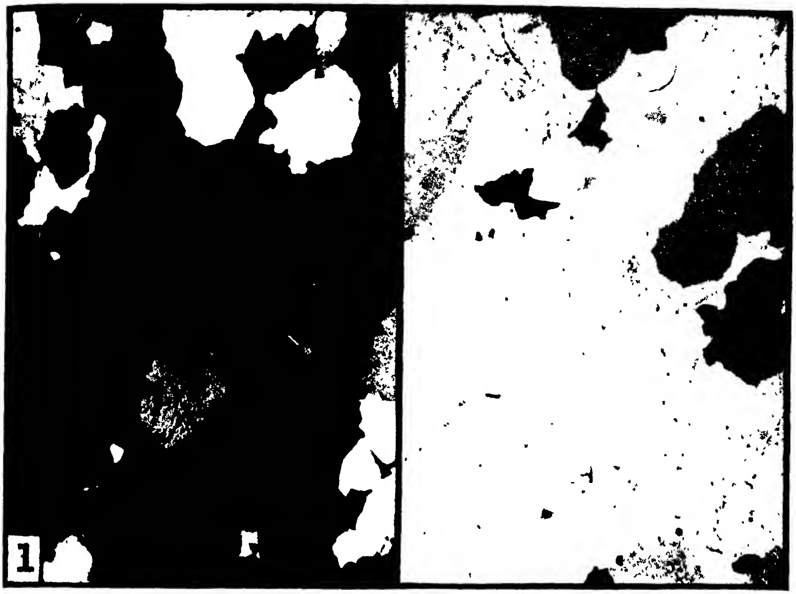
Quartz veins in Moine schists. In the left-hand half of each figure the majority of the grains are near their extinction-position, whilst in the right-hand half the stage has been rotated through 45°.

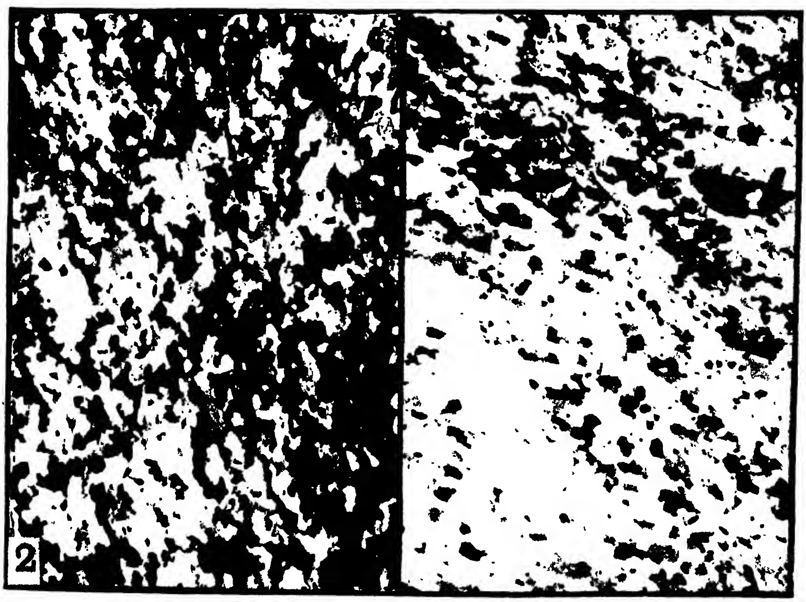
Fig. 1.—Crossed nicols, × 15. Quartz vein in normal Moine schist. Three miles south-west of Achnasheen.

Fig. 2.—Crossed nicols, × 15. Quartz vein in Moine schist affected by the dislocation-metamorphism. South of Attadale River, Loch Carron.



Textures of Moine Schists.





QUARTZ VEINS IN MOINE SCHISTS.

Mooreocrinus and *Ureocrinus* gen. nov., with Notes on the family Cromyocrinidae

By James Wright and Harrell L. Strimple

(PLATE IX)

IN the course of discussions on Echinoderms between the senior and junior authors, the family Cromyocrinidae came under scrutiny and in view of a vital link of evidence in the form of a Pennsylvanian (Upper Carboniferous) specimen of *Ulocrinus buttsi* Miller and Gurley with the arms attached, found by the junior author a few years ago, the following interpretation of the family is suggested.

Bather's conception of the Cromyocrinidae (1900) included the genera *Cromyocrinus* Trautschold, *Eupachycrinus* Meek and Worthen, *Agassizocrinus* Shumard ex Troost, *Tribrachiocrinus* McCoy, *Phialocrinus* Trautschold, and *Ulocrinus* Miller and Gurley.

Jaekel (1918) restricted the family to *Cromyocrinus* and *Ulocrinus*, but since *Cromyocrinus* included species with five simple arms only and others with ten he proposed the new genus *Dicromyocrinus* for the latter group.

Bassler (1938) placed *Dicromyocrinus* into synonymy with *Cromyocrinus*, but Moore and Plummer (1940, p. 353) appear to have accepted *Dicromyocrinus* as a valid genus, since they assign two Upper Mississippian (Chester) species to it.

In their latest work on the evolution and classification of palaeozoic crinoids, Moore and Laudon (1943) accept Jaekel's definition of the family in so far as it includes *Cromyocrinus* and *Ulocrinus*, but they reject *Dicromyocrinus* as a *nomen nuda* on the grounds that no genotype species was selected.

To regularize the position we here propose a new genus to embrace those forms of *Cromyocrinus* having more than five arms.

Mooreocrinus gen. nov.

Genotype : *Cromyocrinus geminatus* Trautschold (1867, p. 25, pl. iv, fig. 6)

The arms in *Cromyocrinus simplex*, the genotype species, number five. In *C. geminatus* and *C. ornatus* the number is ten, and we now separate these two species under *Mooreocrinus* with *M. geminatus* as the genotype species. Bather (1917–18, p. 214) considered *Cromyocrinus geminatus* Trautschold to be a synonym of *Cupressocrinites nuciformis* Fischer von Waldheim (1837, pl. xli, figs. 5, 6) but the figures of the latter species do not quite convince us that the two forms are identical and we accordingly retain the trivial name *geminatus* meantime. Outside Russia *M. geminatus* occurs in Scotland in the Encrinite Bed, St. Andrews (Wright, 1934, p. 243) and a new Cromyocrinoid genus *Tyrieocrinus*, with *T. laxus* as the genotype species, has recently been described from the Seafield Tower Limestone of the midland region of Scotland (Wright, 1945, p. 114). Moore and Plummer (1940, text-fig. 5) give a generalized subdivision

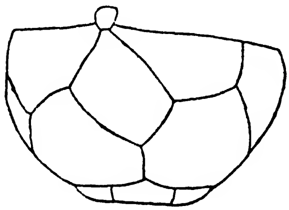
of crinoid cups according to shape, wherein *Cromyocrinus* is placed under group A III (c). This is essentially a group with the cup low (height to width ratio), greatest width below summit of cup and IBB unflared. The species we refer to *Mooreocrinus* are included therein under *Dicromyocrinus*, group B III (c) ; this includes forms with the cup medium, globe shaped, greatest width below summit of cup and having sub-horizontal IBB. The group under consideration is more intimately dealt with by Moore and Plummer in their text-fig. 69. Pending further information we see no reason for not following this formula and therefore assign *C. grandis* and *C. globosus* to *Cromyocrinus* and *C. hemisphericus* and *C. papillatus* to *Mooreocrinus*. The following species have been referred to *Cromyocrinus* :—

	Age	*Present Generic Position*
Cromyocrinus simplex Trautschold.	Mississippian, Russia.	*Cromyocrinus* Trautschold (genotype)
C. grandis Mather.	Lower Pennsylvanian (Morrow), Kansas.	,,
C. globosus (Worthen)	Upper Mississippian (Chester), Illinois.	,,
C. geminatus Trautschold.	Mississippian, Russia and Scotland.	*Mooreocrinus* gen. nov. (genotype).
C. ornatus Trautschold.	Mississippian, Russia.	,,
C. hemisphericus (Worthen).	Upper Mississippian (Chester), Illinois.	,,
C. papillatus (Worthen).	Upper Mississippian (Chester), Illinois.	,,
C. buttsi (Miller and Gurley of Keyes).	Middle Pennsylvanian, Missouri.	*Ulocrinus* Miller and Gurley (genotype).
C. sangamonensis (Meek and Worthen).	Middle Pennsylvanian, Illinois.	,,
C. kansasensis (Miller and Gurley of Keyes).	Middle Pennsylvanian, Missouri.	,,
C. gracilis (Wetherby).	Upper Mississippian (Chester), Illinois.	*Phanocrinus* Kirk.

ULOCRINUS Miller and Gurley

Before discussing this genus a brief description is here given of the specimen of *U. buttsi*, referred to in the introduction and illustrated on Plate IX and text-fig. 5. Before the discovery of this specimen the arms were not known in any American species of *Ulocrinus*, except small portions in *U. convexus* (Strimple) (Strimple, 1939, pl. i, figs. 12, 16). The present specimen is flattened from posterior to anterior. The shape of the cup and the anal structure, with the RA completely detached from the right posterior basal, are typically that of *U. buttsi*. In this specimen, however, the RA is separated from LPR and anal X is a large plate which touches post. B. In this respect there is a slight difference from the figure of the holotype as given by Miller and Gurley (1890, pl. i, fig. 5) and by Bather (1900, text-fig. xxix). Our text-fig. 4 is a reproduction from these figures. Here RA has a wide junction with LPR and is surmounted by a comparatively small anal X. It does not appear, however, that the holotype has been examined in recent years, since we can find no reference to it.

Specimens of this species, in fact, are very rare. Few are known and the slight difference in the anal area in the present specimen seems to indicate that, were more specimens available, we might expect to find some variations of the kind noted. In the new specimen the IBB look rather high, but this is illusory and due to the squeezing out of the plates. There is also a gap between X and RPR, which is caused by displacement ; it was not occupied by a plate. It has, of course, been impossible for us to examine the holotype of *U. buttsi*, but under present circumstances we feel



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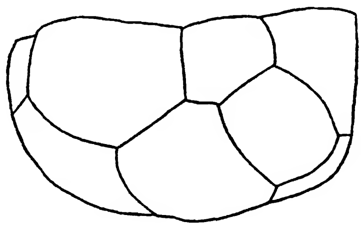

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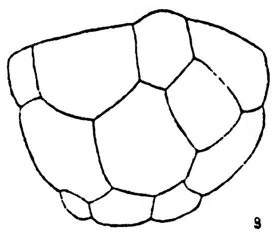

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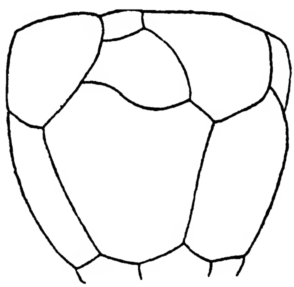

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TEXT-FIGS. 1, 3, and 4.—American species of *Ulocrinus* : fig. 1, *U. kansasensis* Miller and Gurley ; fig. 3, *U. sangamonensis* (Meek and Worthen) ; fig. 4, *U. buttsi* Miller and Gurley. Fig. 2, *Parulocrinus blairi* (Miller and Gurley), after Moore and Plummer. All figs. nat. size.

justified in assigning the new specimen to this species while at the same time noting the slight difference in the anal structure.

The arms are incomplete as to length but apparently did not exceed ten in number. They branch on the first primibrach. The sutures between the secundibrachs are for the most part parallel with a tendency to be cuneiform. The longest arm on the posterior side is the left ramus of right posterior ray, where twelve secundibrachs can be counted. On the anterior ray eight secundibrachs are preserved in both rami. Measurements of the specimen—

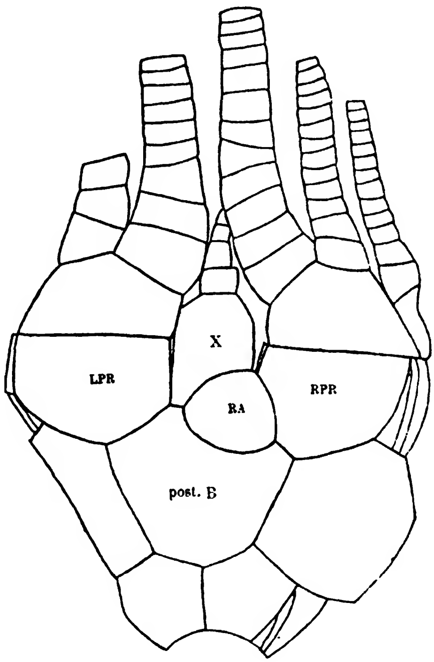
Maximum width of cup	35·2 mm.
Minimum width of cup, post. to ant. .	16·5 mm.
Overall length of specimen . . .	54 mm.
Height of cup	26 mm.
Length of longest arm (left ramus of right post. ray)	28 mm.

Locality.—The Mound, west of Bartlesville, Oklahoma.

Horizon.—Wann Formation (Missouri Series, Ochelata Group), Pennsylvanian.

Collection.—H. L. Strimple.

The above specimen shows that in *U. buttsi* the arms are of a multiple nature, at least ten in number, and this is probably also the case in other American species of the genus. Evidence in support of this idea is given by the young specimen of *U. convexus*, figured by Strimple and already alluded to. Here there was observed axillary primibrachs and a single row



TEXT-FIG. 5.—*Ulocrinus buttsi* Miller and Gurley, from the Mound, Bartlesville, Oklahoma, H. L. Strimple Coll., approx. × 1½.

of secundibrachs in the left posterior and right posterior rays. In the European species *U. bockschii* (Geinitz) and *U. doliolus* Wright the arms, as shown by at least four Scottish specimens of the former species and two of the latter, are five only. In the American Pennsylvanian species *U. kansasensis* Miller and Gurley and *U. sangamonensis* (Meek and Worthen), and in the American Permian species, *U. americanus* (Weller) (re-analysed by Moore and Plummer, 1940, pp. 338–340, pl. 19, fig. 6, text-fig. 6), the arms are not yet known but the cups of these species are consistently larger than the European forms and possibly indicate that the arms are also of a multiple character. (The remaining American species *U. occidentalis* Miller and Gurley is named from an IBB circlet and basal

plate only.) The arms are not known in *U. uralensis* Yakovlev, ? *U. indicus* Wanner, ? *U. conoideus* Wanner, and *U.* ? *goliathus* (Waagen), but in shape the cups of these species, excepting perhaps that of ? *U. conoideus*, have more in common with American than with European species. The anal area in the American, Russian, Timor, and Indian species is of the advanced type and is specially so in *U. buttsi*, where it reaches a stage that might be called super-advanced (Text-figs. 1–4). Little variation in the anal area of the different species appears to have been observed. It seems probable, however, that when large series of specimens are compared some variations will be noted. There is some evidence for this in the specimen of *U. buttsi* now illustrated (Plate IX, figs. 8, 9, Text-fig. 5). In the European species *U. bockschii*, while the predominant anal structure is of the advanced type, specimens are known which on the one hand exhibit a primitive type of anal area, others a super-advanced type similar to and foreshadowing the anal area of *U. buttsi* with intermediate forms among them (Wright, 1927, p. 353). In the past doubts have been expressed about the propriety of placing *U. bockschii* under *Ulocrinus*, but there seemed no other genus to which it could be referred. Apart from the much greater variation in the anal area and shape of the cups, we now know that the arm structure of this species, as well as that of *U. doliolus*, is quite different from that of the genotype species *U. buttsi*. We therefore propose to separate these two European species under the name of *Ureocrinus*, in honour of the Rev. D. Ure, who was probably the first to illustrate a specimen of *U. bockschii* in his *History of Rutherglen and East Kilbride*, 1793, pl. xviii, fig. 12. Ure's figure shows a somewhat flattened cup from the anterior side.

UREOCRINUS gen. nov.

A Cromyocrinid with globular, sub-globular, or somewhat elongated cup ; IBB circlet plainly visible from side ; RR circlet often constricted ; anal area for most part of advanced type with large RA surmounted by one or two small plates ; arms five, brachials cuneiform.

Genotype.—*Poteriocrinus bockschii* Geinitz (1845, p. 548, pl. xxiii, figs. 13*a*, 13*b*).

UREOCRINUS BOCKSCHII (Geinitz)

Plate IX, Figs. 1–5, 7, 10

Ulocrinus bockschii (Geinitz), Wright, 1927, pp. 353–372, text-figs. 1–57 ; Wright, 1939–1940, pp. 28–30, pl. vi, figs. 2, 7, 8, text-figs. 19–30.

Cup sub-globular to elongate globular ; IBB circlet rather high and always visible from side ; BB tumid ; RR somewhat constricted ; anal area predominantly of advanced type, RA having a wide junction with right post. B and left post R and usually surmounted by one or two small plates, X and RX ; a small percentage exhibit a more primitive type of anal area and a still smaller percentage a super-advanced type ; arms five, pinnules short, brachials cuneiform.

Holotype.—In Germany ?

Localities.—Britain and Germany (for list of localities in Scotland see Wright, 1939–1940, p. 29).

Horizon.—Lower Carboniferous (Upper part of Mississippian).

Remarks.—The cup figured by Geinitz as *Poteriocrinus bockschii* (1846, pl. xxiii, figs. 13*a*, 13*b*) should probably be regarded as the holotype and is presumably in Germany. We consider specimens Nos. 2358 a–r J. W. Coll. from No. 1 Bed, Invertiel, and Nos. 2123, 2345, J. W. Coll., from Penton Linns, Liddesdale, to represent the species. Geinitz's figures show a typical sub-globose cup in which RA is a conspicuously large plate, having a wide connection with right post. B and LPR and surmounted by at least one small plate, possibly two, but the figure is a right antero-lateral view and only one can be seen. This structure is typical of the cups figured by McCoy as *Poteriocrinus nuciformis* (1855, pl. 3D, fig. 4), by de Koninck as *Hydreionocrinus globularis* (1858, pl. iv, fig. 1)—although RA here is surmounted by one plate only—and by W. E. Schmidt as *Ulocrinus bockschii* (Geinitz) (1930, pl. 3, figs. 17a, 18a). It is interesting to note that in Schmidt's figures the RA is surmounted by two small plates (X and RX), which vary as to size and shape, as also does the RA. The range of variations in the Scottish specimens has already been recorded (Wright, 1927, p. 383). It might be thought by some workers that it is stretching a point to include cups showing a primitive type of anal area with the more advanced types in a single species. For the present, however, all these forms are retained within the one species group, since experience with this species, as well as with large numbers of the associated species *Phanocrinus calyx* McCoy, *Zeacrinus konincki* Bather, *Decadocrinus fifensis* Wright, and *Hydreionocrinus woodianus* de Kon. (Wright, 1926, pp. 145–164, 1934, pp. 247–250, text-figs. 6–18 ; 1939–1940, pp. 26–27), indicates that we are here dealing with an extremely plastic group of forms which, in an evolutionary sense, were very susceptible to changes of habitat and environment. This aspect of the subject is being further studied, and it is perhaps significant that the variations from the norm are most pronounced in the specimens from one horizon, viz. the Seafield Tower Limestone in which there is evidence, in the crinoid bearing shales above the limestone, at Seafield, Invertiel, etc., of unsettled conditions during their deposition—contemporaneous erosion, thickening, and thinning out of the beds, etc. At Roscobie and Charlestown, etc., there is also evidence of bioherm conditions during the deposition of the limestone itself. Whether these were the main factors or not, we see in the species mentioned, *Phanocrinus calyx*, *Zeacrinus konincki*, *Decadocrinus fifensis*, and *Hydreionocrinus woodianus*, especially the first three, a great range of variation in anal structure and shape of the cup. A not dissimilar state of things, although in a less degree, is seen in *Ureocrinus bockschii*. For comparison the variations from the norm in all the above species are here tabulated.

	No. examined	Percentage of variations	Norm
Phanocrinus calyx	1,000 +	approx. 30	Primitive
Zeacrinus konincki	342 +	„ 30	Advanced
Decadocrinus fifensis	43 +	„ 33⅓	Primitive
Ureocrinus bockschii	542 +	„ 10	Advanced
Hydreionocrinus woodianus	60 +	„ 2½	Primitive

The question may be asked, why should these variations be so pronounced in the Scottish species as compared with congeneric species in America? It cannot be for lack of material, since Kirk has examined many cups of *Phanocrinus* from the United States and has found nothing comparable with the Fife forms (Kirk, 1937, p. 603). He seems to agree that in the Scottish *Phanocrinus calyx* (and presumably in the other species) we are dealing with a species complex which entered the area and being exceedingly plastic responded quickly to the stimulus of changes of environment, etc. So far as known, *Ureocrinus bockschii* and *U. doliolus* are confined to the European Lower Carboniferous (Mississippian). *U. doliolus* has already been described (Wright, 1936, pp. 404–407, text-figs. 28–32, pl. ix, fig. 5; 1939–1940, p. 30, text-figs. 31–5, pl. ii, fig. 2, pl. viii, fig. 12). It differs chiefly from *U. bockschii* in having a more elongated cup, higher and less tapering IBB circlet. The arms are more slender and apparently reached a greater length. The following table shows the species which have been referred to *Ulocrinus* and their present generic position.

ULOCRINUS Miller and Gurley (1890)

Species which have been recognized as Ulocrinus.	*Age.*	*Present generic position.*
Ulocrinus buttsi Miller and Gurley.	Middle Pennsylvanian, Missouri.	*Ulocrinus* (genotype species).
U. sangamonensis (Meek and Worthen).	Middle Pennsylvanian, Illinois.	,,
U. kansasensis Miller and Gurley.	Middle Pennsylvanian, Missouri.	,,
U. americanus (Weller).	Lower Permian, Texas.	,,
U. convexus (Strimple).	Middle Pennsylvanian, Oklahoma.	,,
U. occidentalis Miller and Gurley.	Pennsylvanian, Missouri.	? ,,
U. ? goliathus (Waagen).	Permian, India.	? ,,
? *U. indicus* Wanner.	Permian, Timor.	? ,,
? *U. conoideus* Wanner.	Permian, Timor.	? ,,
U. uralensis Yakovlev.	? Pennsylvanian (Permo-Carboniferous), Russia.	,,
U. blairi Miller and Gurley.	Middle Pennsylvanian, Missouri.	*Parulocrinus* Moore and Plummer (genotype species).
U. bockschii (Geinitz).	Mississippian, Germany and Great Britain.	*Ureocrinus* gen. nov. (genotype species).
U. doliolus Wright.	Mississippian, Scotland.	,,
U. globularis (de Kon.).	Mississippian, Great Britain.	syn. *U. bockschii.*
U. nuciformis (McCoy).	Mississippian, Great Britain.	syn. ,,

Proposed classification of the Cromyocrinidae :—

Genus : *Cromyocrinus* Trautschold.

Genotype : *C. simplex* Trautschold. 5 arms.

Genus : *Tyrieocrinus* Wright.

Genotype : *T. laxus* Wright. ? 5 arms.

Genus : *Mooreocrinus* n.g.
Genotype : *M. geminatus* (Trautschold). 10 arms.
Genus : *Ulocrinus* Miller and Gurley.
Genotype : *U. buttsi* Miller and Gurley. 10 arms.
Genus : *Ureocrinus* n.g.
Genotype : *U. bockschii* (Geinitz). 5 arms.

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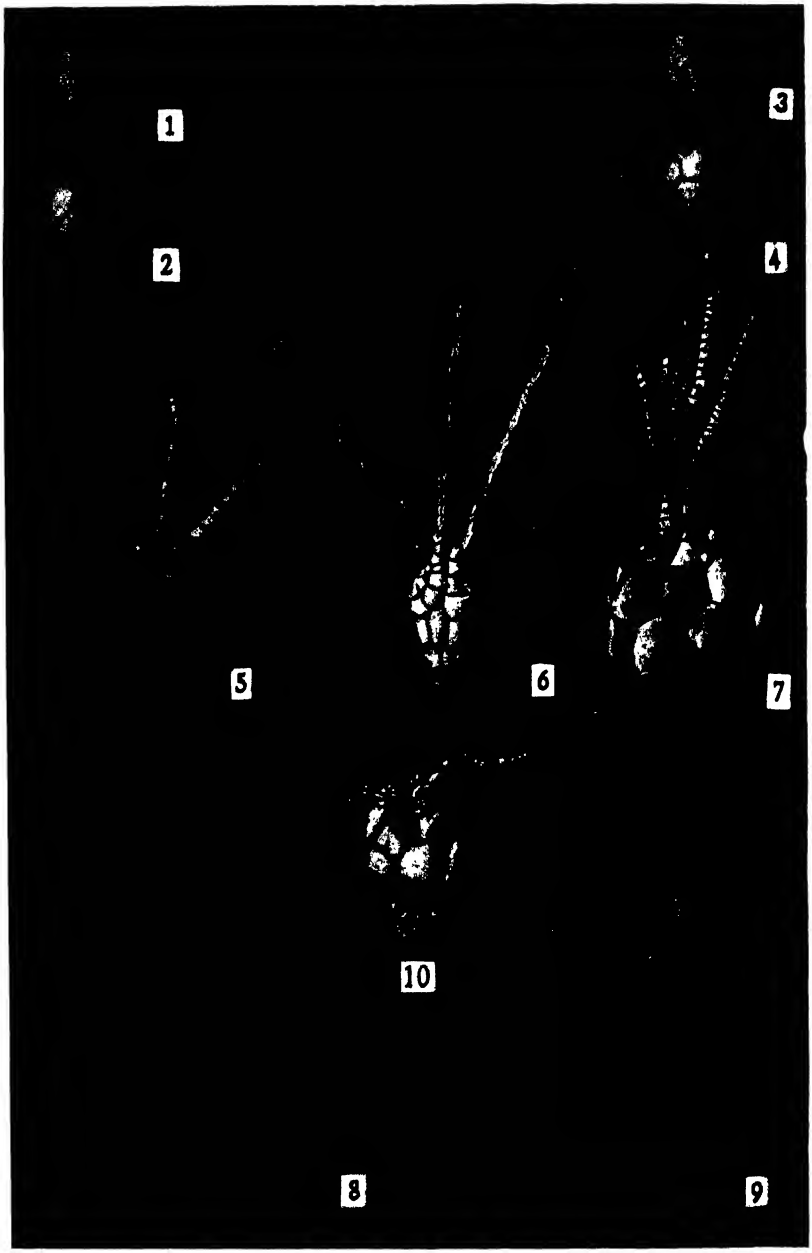

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EXPLANATION OF PLATE IX

FIGS. 1–4.—*Ureocrinus bockschii* (Geinitz) from No. 1 Bed, Invertiel, showing variation in anal area and shape of cups; Nos. 2358 a, c, b, d, J. W. Coll.

FIGS. 5 and 7.—*Ureocrinus bockschii* (Geinitz) from Penton Linns, Liddesdale; somewhat crushed crows showing arm structure, etc.; Nos. 2123, 2345, J. W. Coll.

FIG. 6.—*Ureocrinus doliolus* (Wright) from Encrinite Bed, St. Andrews; the holotype No. 1093, J. W. Coll.

FIGS. 8 and 9.—*Ulocrinus buttsi* Miller and Gurley; a somewhat flattened crown from the Mound, Bartlesville, Oklahoma, U.S.A., H. L. Strimple Coll., showing arm structure, etc.; fig. 8, anterior view, fig. 9, posterior view.

FIG. 10.—*Ureocrinus bockschii* (Geinitz) from Penton Linns, Liddesdale; J. L. Begg Coll., Geological Department, University of Glasgow, No. E 3435; part of one arm is fairly well preserved in this specimen. All figs. nat. size, except figs. 8 and 9 which are approx. × 1½.

Thanks are here accorded to Dr. Ethel D. Currie for the loan of the specimen of *Ureocrinus bockschii* illustrated in fig. 10.

The Distribution of Trace Elements in a Scottish Permo-Carboniferous Teschenite and its Lugaritic Differentiate

By Edward M. Patterson

Introduction

In a recent description of a composite teschenite-picrite sill at Saltcoats in Ayrshire (Patterson, 1945), mention was made of a potash-rich variety of lugarite which occurs as a differentiate of biotite-teschenite. The latter rock was emplaced at an intermediate stage in the intrusion cycle of the sill, being preceded by a flow-banded teschenite and followed by hornblende-picrite. Differentiation of the biotite-teschenite took place in situ and had proceeded to a considerable extent before the picrite was intruded along the middle portion of the former rock, splitting it into an upper and a lower layer. Richness in volatile constituents was a characteristic of the biotite-teschenite magma and facilitated the process of differentiation (Tomkeieff, 1937, p. 85 ; Smyth, 1913, p. 33). The separation of an alkali-rich fraction which resulted, is seen in the field by the appearance of pink analcitic patches or " blebs " in the teschenite at a distance of a foot or so from the margins. Further from the contacts, where cooling conditions were more gradual, these analcitic areas increase in size and frequently coalesce to form veins, which themselves intrude adjacent areas of biotite-teschenite. The veins are pink in colour, and contain varying amounts of conspicuous acicular crystals of barkevikite and titanaugite. Petrologically they are similar to the lugarites of the Scottish Permo-Carboniferous suite (Tyrrell, 1917). In chemical composition they also resemble the type lugarite, with the important exception that the Saltcoats rock is much richer in potash, although the sum of potash and soda is little different. A close analogy is provided by covite, from Magnet Cove in Arkansas (Washington, 1901). On account of the close relationship of the Saltcoats rock to the Scottish teschenites, it was preferred to name the rock potash-lugarite.

The chemical analyses of the biotite-teschenite and potash-lugarite contained in the author's paper (1945) have been supplemented by determinations of some of the rarer elements contained in the two rocks using the cathode-layer-arc spectrographic method. For a description of the technique employed the reader is referred to a recent paper on the Skaergaard rocks of East Greenland (Wager and Mitchell, 1943).

Composition of the biotite-teschenite magma

The analysed sample of the biotite-teschenite was taken from near its contact against the earlier flow-banded teschenite, and as it is free from analcitic " blebs ", it may be regarded as representative of the undifferentiated rock. The accompanying table contains the chemical and spectrographic analyses, in the form of oxides, of the teschenite and the lugarite. The major constituents are given in normal type, and the results for the trace elements in heavy type. The order adopted is that of increasing ionic radius of the element, since this constant is an important factor in deciding the eventual distribution of the elements during the

crystallization process. The chemical analyses, already given in percentages (Patterson, 1945) and here reproduced in parts per million, contain results for one or two trace constituents which are here given as spectrographic determinations. The results by the two methods are not identical but are of the same order.

The analysis of the biotite-teschenite shows a close resemblance to other analyses of teschenites of this suite, although its silica percentage places it on the borderline of the picroteschenite class. No analyses are available by which the minor constituents may be compared with other Scottish teschenites, though the results of Noll's average of eleven gabbros, quoted by Wager and Mitchell (1943, p. 286) may be of some interest in this connection. A fair degree of similarity exists in the trace constituents, with the exception of BaO, which is about eleven times as abundant in the Scottish rock. The SrO content is about three times that of Noll's average.

The chemistry of the differentiation process

The control of the structure and characteristics of the crystals formed from a cooling rock magma is determined by the major constituents which are present, and the disposition of the elements present in small quantities is a secondary process. The formation of the crystals depends on the building up of space lattices of ions or atoms in a regular arrangement, which is dependent on the ionic or atomic radii of the individuals (Stewart and Wilson, 1944, p. 269). Into such a lattice only atoms or ions of the appropriate size can enter, and as a result the crystal acts as a kind of sorting mechanism towards the atoms or ions as yet not incorporated within it. Given a table of ionic radii it is possible to predict into what electrovalent crystals or minerals an element is likely to be entering. When the radii are equal, and also the valencies, the chance of the elements entering into the lattice is about the same, thus nickel and magnesium are often proportional in certain minerals. If radii, valencies, and ionic type are similar then no separation by fractional crystallization is able to occur, as in the pairs zirconium and hafnium and yttrium and holmium, where hafnium and holmium are " hidden " (Goldschmidt, 1937).

Where the ionic radii are different, entry into the lattice is more difficult for the larger ion, and similarly exit more easy. This latter results in a lower melting point for the member of a mineral series in which the larger ion is most abundant. For the same reason, rubidium and caesium, as univalent associates of potassium become concentrated in the potash feldspars of pegmatites.

A crystal lattice may accommodate ions having a fitting radius though of a different valency. The order in which such ions enter a lattice depends on the electrostatic charge of the ion, that with the largest charge entering first. Scandium enters into the early crystallizations of magnesium minerals for this reason, and lithium into the later fractions.

The fractional crystallization which has produced potash-lugarite from biotite-teschenite follows the normal course of the picrite-teschenite-lugarite differentiation series. The mineralogical characteristics of the lugarite are in agreement with those quoted by Kennedy (1933, p. 244) for the pegmatitoides of rocks of the olivine-basalt class (as opposed to

the tholeiite class). Comparison with the chemical analyses given in that paper for the two classes of differentiate confirm the association, although in the Saltcoats rock the fractionation appears to have proceeded to a more extreme degree. Tomkeieff (1937) regards the teschenites as derivatives of a primary magma of the olivine-basalt type by the addition of alkalis and volatiles, further differentiation taking place mainly by fractional crystallization, or, to a less degree, by diffusion of the alkali-volatile portion.

The most significant chemical difference between the teschenite and the lugarite lies in the large increase in total alkali content ($Na_2O + K_2O$) which is approximately the same as in the type rock from Lugar. In contrast to the latter, however, the increase in potash has been considerably greater than that of soda. The amount of alumina shows a sharp rise, and together with the small relative rise in silica, results in a markedly undersaturated rock.

The variations in the proportions of the minor constituents will be considered in order of their ionic radii, as in the accompanying table.

Ga_2O_3 is present in a small amount which lies near to the limit of sensitivity. No significant difference in amount was found between the biotite-teschenite and the potash-lugarite. The probable association of gallium with aluminium in aluminosilicates has been noted by Wager and Mitchell (1943, p. 293), but in the present instance the variation of Al_2O_3 between the two rocks is not sufficient to bring up any variations in the Ga_2O_3 content.

Chromium shows a very marked drop in the lugarite, which is in conformity with its occurrence in comparative abundance in ultrabasic rocks (Groves, 1937, p. 189). Goldschmidt's average Cr_2O_3 content for peridotites is 0·5%, for gabbros 0·05%, with correspondingly smaller amounts in the more acid rocks. Chromium, titanium, and vanadium are probably associated with ferric iron in the iron ores, and they reflect the drop in the latter constituent from the teschenite to the lugarite. The smaller size of the chromium ion (Cr^{+++}) compared with Fe^{+++} and the resulting ease of entry of the former into the crystal lattice at an early stage is reflected in the very marked drop referred to in the preceding sentence. The size of V^{+++} is intermediate between Cr^{+++} and Fe^{+++} and consequently the drop in the differentiated rock is less extreme.

Lithium increases sharply in the vein rock, in which it is more than three times as abundant as in the teschenite. Strock (1936) has shown that in spite of its being a member of the alkali metal series it tends to occur mainly in low temperature ferromagnesian minerals, such as the iron-rich pyroxenes, rather than in feldspars. This behaviour is accounted for by its similarity in ionic size to Mg^{++} and Fe^{++}. The ionic radii of Li^{+} and Mg^{++} are too similar to allow the size factor to play a part, but the lower ionic charge of the univalent lithium ion results in its preferential exclusion from the earlier ferromagnesian crystallization. Its concentration in the later fractions of the potash-lugarite is thus explained, although evidence of the mineralogical location is lacking.

Nickel and cobalt are probably present in the ferromagnesian minerals (Wager and Mitchell, 1943, p. 292) and exhibit a fair degree of similarity to the proportions of MgO and FeO in the two rocks. The higher content

of cobalt is interesting, as this element is generally present in smaller amount than nickel.

Goldschmidt (1937) states that scandium enters into the early crystallization of magnesium-containing minerals, having approximately the same ionic radius, but a higher valency. This results in a concentration of this element in the biotite-teschenite rather than in the potash-lugarite.

The content of zirconium shows no change between the two rocks. Wager and Mitchell (1943) regard its presence in the ferromagnesian minerals as unlikely, although the ion belongs to the correct size group and its quadrivalent character might be expected to facilitate its entry into such crystals.

Both strontium and barium are present in large amounts in the teschenite and increase markedly in the lugarite. The increase in strontium in the latter rock is less than barium, which is probably due to the smaller size of the strontium ion relative to barium, thus enabling the former element to enter more easily and rapidly into the crystal lattice of feldspar in place of potassium. The possibility of a less elementary factor operating in the case of barium has been mentioned by Wager and Mitchell, who regard the distribution as the result of interplay between the radius and charge of Ba^{++} in relation to the other positive ions forming feldspars, namely Na^{+}, Ca^{++}, and K^{+}. The larger size of Ba^{++} should produce a concentration in the later feldspars, while the divalent character would have the opposite effect. In the present instance the effect of the size of Ba^{++} appears to be dominant.

Rubidium is probably present in the later feldspars, and increases in the lugarite in sympathy with potassium. The increase is, however, more marked than with the latter element, since the large radius of Rb^{+} would tend to its preferential exclusion during the earlier crystallization of potassium-containing minerals, with its concentration in the later fractions.

Summary

A biotite-teschenite and a lugarite differentiate have been analysed spectrographically for trace elements. The rocks occur as part of a composite sill of Permo-Carboniferous age at Saltcoats, Ayrshire. No comparative figures for other rocks of this suite are at present available, but the teschenite appears to be fairly rich in strontium and barium. The amounts of the trace elements present in the differentiated rock show in some cases very marked differences from those in the parent rock. Chromium and scandium in particular, diminish greatly during differentiation, while lithium and rubidium demonstrate the reverse process. The results have been correlated with the findings of Goldschmidt on the conditions governing the disposition of trace elements in crystallizing rock magmas.

For the two spectrographic determinations contained herein the writer would express his indebtedness to Dr. R. L. Mitchell, of the Macaulay Institute for Soil Research, Aberdeen. Grateful acknowledgment is due also to Dr. G. W. Tyrrell and to Dr. J. E. Richey, for their valuable comments and criticism both in field and laboratory, and to Professor L. R. Wager for reading this paper in manuscript.

ANALYSES OF BIOTITE-TESCHENITE AND POTASH-LUGARITE
SALTCOATS MAIN SILL, AYRSHIRE
(Results expressed in parts per million)

	Ionic-radii in Å.	*Sensitivity.*	*Biotite-teschenite.*	*Potash-lugarite.*
CO_2	0·15	—	4,000	4,000
SO_3	0·30	—	4,000	2,500
P_2O_5	0·33	—	3,400	4,900
BeO	0·34	30	*	*
SiO_2	0·39	—	445,900	485,000
GeO_2	0·44	15	*	*
Al_2O_3	0·57	—	140,000	190,100
Ga_2O_3	0·62	5	**10**	**10**
Cr_2O_3	0·64	1	**150**	**1**
TiO_2	0·64	—	16,600	11,500
V_2O_3	0·66	10	**250**	**15**
Fe_2O_3	0·67	—	44,200	20,100
MoO_3	0·68	1	*	*
SnO_2	0·74	20	*	*
Li_2O	0·78	5	**45**	**150**
MgO	0·78	—	76,400	28,500
NiO	0·78	1	**30**	**15**
CoO	0·82	2	**40**	**20**
FeO	0·83	—	71,600	54,900
Sc_2O_3	0·83	10	**100**	*
ZrO_2	0·87	15	**270**	**270**
MnO	0·91	—	1,500	1,200
Na_2O	0·98	—	31,000	45,500
CaO	1·06	—	102,700	50,500
SrO	1·27	10	**600**	**950**
PbO	1·32	30	*	*
K_2O	1·33	—	20,900	49,100
BaO	1·43	10	**780**	**2,250**
Rb_2O	1·49	30	**30**	**110**

* Indicates that the amount is less than the sensitivity.

Analyst for trace elements : R. L. Mitchell.
Analyst for other elements : E. M. Patterson.

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REVIEWS

THE GEOLOGY OF THE NORTHERN PART OF THE SOUTH STAFFORDSHIRE COALFIELD (CANNOCK CHASE REGION). By G. H. MITCHELL. *Wartime Pamphlet* No. 43. H.M. Geological Survey. pp. 47, with 11 figures. 1945. Price 2*s*. 3*d*.

The region described in this memoir is bounded on the south by the Bentley faults, which run E.–W. just north of Wolverhampton and Walsall, while the northern part forms the well-known Cannock country, with its considerable development of Bunter Pebble Beds. The southernmost part of the Coal Measures is largely worked out, but further north there are about 20 important collieries with an annual output of some 5,000,000 tons.

Coal Measures over nearly all the area lie on Silurian (usually Downtonian) strata, but in one place at Fair Oak pit, N.E. of Cannock, Carboniferous Limestone was met in a heading. The Productive Measures, which begin in the Ovalis zone, are about 1,200 feet thick, a good deal thicker than in the Black Country to the south, but the number of seams is about the same. The supposed equivalents of the Thick Coal of the south are spread over about 150 feet of strata. The Upper Coal Measures (Etruria Marl to Enville Groups) are about 3,000 feet thick : they lie on the west of the field. The Etruria Marl facies here begins in the Similis-Pulchra zone, probably about the middle of it.

There are several marine bands, and mussel bands are well developed, as well as scattered mussels, so that zonal correlations are satisfactory. Faults are numerous, but dips are not usually high. Fossil plants are remarkably scarce. The New Red Sandstone, which varies much in thickness, begins with the Hopwas Breccia.

We have also received two second editions of earlier war pamphlets : High Grade Silica Rocks of the Scottish Highlands and Islands, and Limestones of Scotland, Area IV S.W. Highlands and Islands. It is to be hoped that the Geological Survey will soon be able to resume publication of memoirs in the normal format, instead of these foolscap size reproductions of typewriting on shoddy paper, which are very awkward for permanent preservation in geological libraries.

ECONOMIC GEOLOGY OF CANONBIE COALFIELD. By B. H. BARRETT and J. E. RICHEY. *Wartime Pamphlet* No. 42. Geological Survey of Great Britain, pp. 51, with 9 figures, 1945. Price 2*s*. 6*d*.

This interesting little coalfield, which lies across the Border partly in Dumfries and partly in Cumberland, belongs lithologically mainly to the Scottish Midland Valley facies, especially in the development of the Lower Carboniferous. However, the seams in the Limestone Coal Group are thin and unworkable. The outcrops of the Productive Measures are very small, only about a square mile, but there are possibilities of large reserves

under the upper Barren Red Measures and possibly under Trias. The structures are complex and can only be fully elucidated by further boring. The main coals, which as usual lie in the Ovalis to Similis-Pulchra zones include seven workable seams, one 9 feet thick, totalling 38 feet of coal. The Barren Red Measures belong to the Phillipsi, and, as Professor Trueman thinks, probably in large part to the Tenuis zone. There is no Permian and the overlying New Red Sandstone begins somewhere in the St. Bees series, possibly in the shales.

There are two appendices : on freshwater lamellibranchs, by Professor Trueman ; and on plants, by Dr. Crookall.

The reading of this pamphlet suggests the appropriateness of a mild protest at the confusion prevailing in the nomenclature of the Coal Measures. First we have the old scheme of Lower, Middle, and Upper Coal Measures, which of course is hopeless, as the usage differs in nearly every field, and is never used seriously nowadays. Next comes the botanical classification, with its unfortunate use of the name Westphalian : on the Continent the Westphalian includes the equivalent of nearly all the British Coal Measures and often of the Millstone Grit as well. The more modern substitute, Yorkian, is not satisfactory as it inevitably suggests the city rather than the county, and the city of York is not underlain by Coal Measures : moreover it is an ugly word. Then comes a further modification in the splitting of the Westphalian-Yorkian into Ammanian and Morganian. Last of all we have Professor Trueman's lamellibranch zones, which really do seem to work. In the publication here reviewed, including the appendices, all these classifications, except the first, are mentioned. Further comment is superfluous.

R. H. R.

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Periodical Events in the North Sea Basin

By J. H. F. Umbgrove, Delft, Holland

THE North Sea Basin is enclosed on its western and eastern sides by two axes of elevation, viz. the Pennines (a_5 of Text-fig. 7) and the axis of Erkelenz (a_3). The fault-zone of the Limburg coal district broadens towards the north-west into the graben of the central Netherlands. In the opposite direction it is connected with the Rhine-graben. The southern border of the North Sea Basin is formed by the Brabant Massif. It dates from at least pre-Carboniferous times, but its influence as a geanticlinal ridge of elevation was manifest in many Mesozoic and Cenozoic epochs. In a voluminous memoir Stevens (6) pointed out that the present morphology of Belgium—e.g. the pattern of the rivers—still reveals the influence of this important element.

It is worth while to consider three different aspects of the basin's geological history. For it will be seen that three groups of data converge towards the same conclusive evidence.

In the first place the rate of sedimentation in the basin will be considered. And it will be demonstrated that the notion of certain periods of accelerated and retarded bottom-movements already follows from a comparison of the sedimentation during various time-intervals.

Secondly, this result will be confirmed by a further consideration of the paleogeographic development of the basin.

Finally it will be shown that the principal phases in the structural history of the region are synchronous with tectonic epochs of world-wide importance.

(1) Rate of Sedimentation

The basin of the North Sea belongs to the discordant type of basins according to our classification. It contains a sedimentary sequence ranging from Upper Permian deposits to Pleistocene. In the opinion of Van Waterschoot van der Gracht the post-Carboniferous sediments total about 7,500 metres, or possibly even 9,000 metres. These figures correspond to an average rate of sedimentation of 0·4 centimetre per century, as shown by Table A.

Now the older formations are only known from deep borings along the

TABLE A

RATE OF SEDIMENTATION IN THE NORTH SEA BASIN

Formation	Duration in million years	Maximal thickness of sediment in metres	Average rate of sedimentation in cm. per century
Cenozoic . .	62·5	Largely exceeding 1,000	Largely exceeding 0·16
Cretaceous . .	40·6	> 3,500	> 0·86
Jurassic . . .	43·7	appr. 1,500	appr. 0·34
Triassic . . .	37·5	appr. 1,300	appr. 0·35
Permian . . .	37·5	250–600	0·07–0·16
Post-Carboniferous formations	222	7,500–9,000	0·4
Minimum rate of sedimentation . . .			0·07
Maximum rate of sedimentation . . .			> 0·86

edge of the basin. The data for the Mesozoic, therefore, have been interpolated from what is known of the basin of North-Western Germany.

On the other hand, the figures for the Cenozoic pertain to the North

TABLE B

RATE OF SEDIMENTATION IN A FEW "FOSSIL" BASINS AND TROUGHS

Idiogeosynclines of the East Indies	Duration in million years (approx.)	Maxim thickness in metres	Average sedimentation in cm. per century
Neogene of Indragiri, Sumatra	60	2.000	0·66
,, Djambi, Sumatra .		4,000	1·3
,, Palembang, Sumatra		6,000	2·0
,, Atcheen, Sumatra		6,800	2·2
,, Koetei, Borneo .		7,000	2·3
Tertiary of S. Celebes . .	60	> 4,000	> 0·66
,, Tidoengsche landen, Borneo . .		7,000	1·1
,, Atcheen, Sumatra .		9,500	1·6
,, Pasir, Koetei, Borneo		1,500	2·5
Minimum rate of sedimentation			0·66
Maximum rate of sedimentation			2·5
Jurassic in basin of Paris .	50	1,200	0·24
Low-Cretaceous to Pleistocene of Gulf Coast Basin . .	100	8,000	0·8

Sea basin proper, where sedimentation in Tertiary and Pleistocene times[1] largely surpassed the sedimentation in the basin of North-Western Germany. So the figure 0·4 of Table A probably is on the high side.[2]

Table B reviews a number of data enabling a comparison to be made with the rate of sedimentation in some other " fossil " basins and troughs. Some examples have been gathered from regions which generally are thought to show large amounts of sediment deposited in a comparatively short time.

The average rate of subsidence and sedimentation in the North Sea Basin is only half of that of the Gulf Coast Basin, but is more than twice the movement of the Paris basin in Jurassic times. The movement of the East Indian geosynclinal oil-troughs surpassed largely that of the North Sea basin.

Table C offers a further means of orientation and comparison. It summarizes some data concerning the rate of sedimentation in some of the present oceanic areas.

TABLE C

RATE OF SEDIMENTATION IN THE DEEP-SEA IN CENTIMETRES PER CENTURY. FROM DATA OF THE LORD KELVIN, METEOR AND JOHN MURRAY EXPEDITIONS

Type of deep-sea sediments	Since close of the Pleistocene 20,000 years ago		During last glaciation	During the Pleistocene
	In tropical part of Indian Ocean	In tropical, equatorial part of Atlantic Ocean		
Blue mud	—	0·178	0·33	—
Globigerina-ooze	0·059	0·12	0·21	0·03–0·06
Red deep-sea clay	—	—	—	—
Diatom-ooze	0·054	—	—	—
Min. rate of sedimentation	0·025	0·05–0·09	0·21	0·03
Max. rate of sedimentation	0·07–0·1	0·13–0·33	0·33	0·06

It is generally known that sedimentation in the deep sea is very slow. Now the figure 0·33 which was found for the equatorial regions of the Atlantic differs only slightly from the average figure 0·4 of the North Sea basin.

The first named figure, however, rests on recent marine sediments, which hardly suffered the influence of compaction in contrast to the sediments of the North Sea basin and older strata.

Much higher figures, however, result if only the more recent history of

[1] The basin's subsidence in the Tertiary and Pleistocene is illustrated by Text-figs. 1–4. See also the coloured map accompanying Van Waterschoot van der Gracht's paper of 1938.

[2] In the south-western part of the Netherlands the thickness of post-Paleozoic formations amounts only to 1,200–1,500 metres, which would correspond with an average of 0·05–0·07 centimetre per century.

the North Sea basin be considered. Again some data have been summarized, in Table D.

TABLE D

RATE OF SUBSIDENCE AND SEDIMENTATION IN THE NORTH SEA BASIN DURING PLEISTOCENE AND HOLOCENE TIMES, COMPARE TEXT-FIGS. 5 AND 6.

Average subsidence of the bottom in the N.W. of the Netherlands	Duration in years	Positive shift of the coast line in metres	Average subsidence in cm. per century
Pleistocene plus Holocene	600,000	300	5
From basis Riss-glacial to recent . . .	200,0^0	80	4
Holocene . . .	20,000	22	11
According to data from tide gauges . .	appr. 50	0·15	30

These data point to an abnormally high rate of sedimentation if compared with the figures of Tables A–C.[1] It seems obvious to suppose that the high figures 4 and 5 of Table D are the expression of the abnormal sequence of events in the Pleistocene. Three factors may have been of special influence, viz. (1) subsidence of the peripheral belt around the last Scandinavian ice-cap, (2) compaction of the sediments, (3) rise of the sea-level as a result of the melting of the continental ice-caps.

Anyhow, these figures clearly show that certain epochs are characterized by a much accelerated movement of the bottom as contrasted to the average 0·4 centimetre per century. This result is well in accordance with the paleogeographic data known from the same region.

(2) Paleogeographic development

The maps for Lower, Mid, and Upper Pliocene reproduced in figs. 1–3 show a gradual retreat of the coast line. This phenomenon must be ascribed to a rising bottom movement, which proceeded from the south (Rhine-shield) in a northern direction. But in the Pleistocene—Text-fig. 4—when the growing ice-caps caused a world-wide lowering of the sea-level, the coast line moves in a southern direction instead of continuing its retreat. Hence we may conclude that the rising bottom-movement of the Pliocene was followed by a subsidence of the bottom in the Pleistocene. The influence of strong differential movements along the faults bordering the graben (b1, b2, and b3 on Text-fig. 7) is well illustrated in the map for the Pleistocene (Text-fig. 4). A similar action along the major faults is known also from the Pliocene and Miocene.

The maps for Günz glacial and Günz-Mindel interglacial show a retreat of the sea well outside the present North Sea coast of Holland (Text-figs. 5 and 6). It follows from these data that the rate of the subsiding bottom-movement was at least retarded at that time.

[1] As a matter of fact, Kuenen and Neeb found an average rate of sedimentation of as much as 5 (even 6·5) centimetres per century for the deep-sea basins of the East Indies. Again, however, this concerns recent marine sediments which are not influenced by compaction.

In the boundary region of the North Sea basin a Pleistocene tilting may be deduced from the arrangement of fluviatile deposits. The rivers entrenched themselves in the deposits of a previous period. Thus the well-

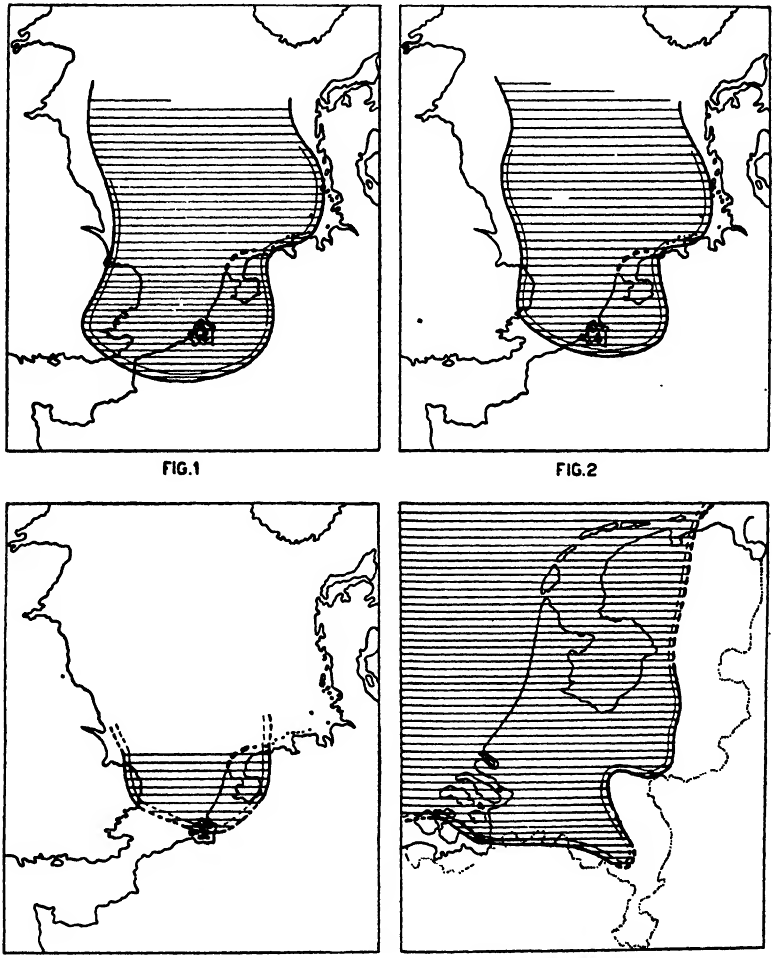


FIG. 1 FIG. 2 FIG. 3 FIG. 4

TEXT-FIGS. 1–4.—Pliocene and Pleistocene paleogeography of the North Sea Basin (after P. Tesch, op. cit., 1942). Fig. 1, Lower Pliocene ; fig. 2, Mid-Pliocene ; fig. 3, Upper Pliocene ; fig. 4, Lower Pleistocene.

known sequence of fluviatile terraces was formed along the incised channels of the streams, the age of the terraces diminishing from Lower Pleistocene to Subrecent if one proceeds from the highest terrace to the lowest. In the subsiding basin, however, the sediments have been deposited

in the opposite order, the more recent sediments on top of the older ones. The result of these circumstances is a remarkable crossing of the terraces.[1]

From the available data a similar tilting of the bottom may be deduced for two other epochs, viz. (1) post-Lias and pre-Senonian, (2) Oligocene. The pre-Senonian warping was correlated by de Sitter with the Upper Cimmerian epoch of compression. The Oligocene movement was synchronous with one of the principal phases of folding of the Alps. Moreover, both the epochs are marked by major phases of movement

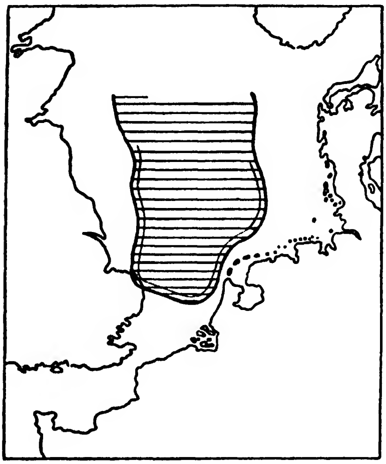


FIG 5

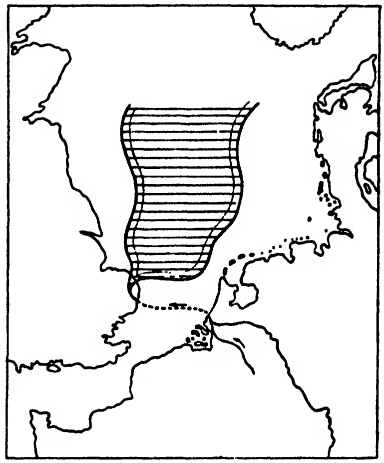


FIG 6

TEXT-FIGS. 5–6.—Paleogeography of the North Sea Basin in late Günz-glacial times (fig. 5) and during the Günz-Mindel interglacial (fig. 6). (After P. Tesch, op. cit., 1942.)

along the faults of the Southern Netherlands, by the formation of the present Rhine-graben, etc.

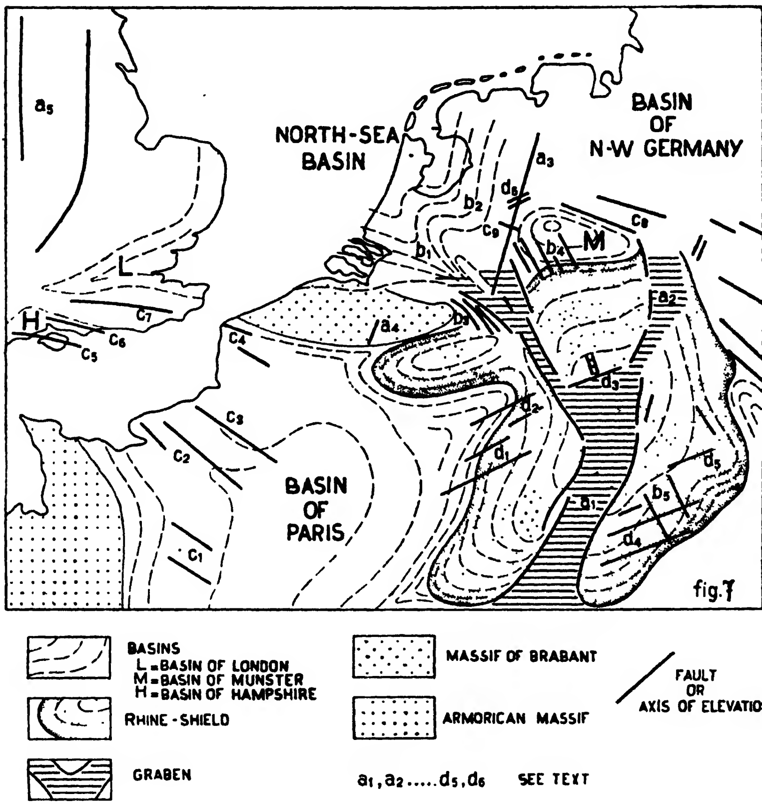
(3) Structural History

In short, the most important phases of movement of the North Sea basin, the Rhine shield, and the intermediate fault zone appear to be inter-related. And these movements can be correlated with movements in the earth's crust, which are known to be of world-wide importance. Again and again we see that special epochs, marked by compression and folding in geosynclinal belts, are characterized by important processes outside the geosynclinal zones as well.

Finally a few examples concerning the structural history of the same district may be added. The time of origin of the North Sea basin as such, especially of its eastern and western boundaries, coincides with the Lower

[1] See K. Oestreich, op. cit., 1938, p. 555, fig. 1. See also R. A. Daly, *Changing World of the Ice Age*, 1934, p. 189, and fig. 100 on p. 190.

Cimmerian phase (a_2 and a_5 of Text-fig. 7) ; a preliminary indication of their formation coincides with the Saalian phase. The formation of the basin of Paris dates from the Lower Cimmerian phase. The Munster basin originated contemporaneously with the Upper Cimmerian origin of numerous faults and so-called anticlinal ridges in the basin of Paris, the Boulonnais, the Weald, and the Egge and Osning (c_1–c_8). The same epoch



Text-fig. 7.—Major tectonic elements in the surroundings of the North Sea Basin.

is marked by important tectonic movements along the Limburgian faults (b_3). The first appearance of the London basin, as a south-western prolongation of the North Sea basin coincides with the Laramide phase, etc. A few more examples of correlation are combined in Table E.

(4) General Conclusions

From these facts we may deduce that all these phenomena are interrelated and depend on a common cause, which resides in the deeper substratum. The chronological relation between epochs of mountain

building—i.e. epochs of decreasing compression in the earth's crust—and the origin of basins was mentioned as a striking result of our examination in chapter iv (p. 54) of *The Pulse of the Earth* ; the dome-shaped elevations with their faults and rift-systems, were incorporated in the series of periodic events. Once a basin or a zone of elevation has come into being it is rejuvenated during one or more later epochs. And these epochs are marked generally by a rising tendency of folded mountain-chains, i.e. the epochs immediately succeed a time of compression. On the other hand, it is clear for evident reasons that the origin of faults may be contemporaneous with an epoch of compression.

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Evidence for a New Major Fault in North-East England [1]

By A. Fowler

THE Magnesian Limestone of England forms a comparatively narrow outcrop stretching southwards for about 150 miles from South Shields to Nottingham. At either end the formation is fairly well known from the many quarries and sections opened up in the industrial areas of East Durham on the one hand and South Yorkshire and Nottinghamshire on the other. Away from these regions, however, our knowledge is scanty, and particularly so in the North Riding of Yorkshire, in the tract of country between the rivers Tees and Swale. Information is lacking mainly because the district is so thickly covered with Glacial and Recent deposits that, except at the extreme ends of this Tees-Swale stretch, rock is nowhere exposed. All the way from the Darlington country down to Catterick and beyond, for sheer lack of evidence the Trias—Magnesian Limestone boundary was assumed to be of normal, unfaulted character, but all was so uncertain that any borings in the area were likely to prove invaluable. How invaluable will be gathered from the following account of two recent bores, which throws an entirely new light, not only on the geological structure but also on the stratigraphy of this obscure region.

The bores lie on either side of the River Swale and the sites are shown on the map (Text-fig. 1). The more southerly of the two—that at Catterick, sited at 185 feet O.D.—was 170 feet deep and although 100 feet of this is in " drift " the remaining 70 feet showed a highly characteristic rock sequence. The great bulk was crinoidal limestone with brachiopoda of pronounced Carboniferous type. From the bottom 15 feet of limestone Dr. Stubblefield has identified fossils including *Fenestella*, *Productus* (*Krotovia*) *aculeatus* (Martin), *P.* (*Dictyoclostus*) *muricatus* Phillips, and *P.* (*Buxtonia*) *scabriculus* (Martin), as well as several species of *Phricodothyris*. Sponge spicules and anchoring spines referred to *Hyalostelia smithi* (Young and Young) were particularly abundant, especially in siliceous mudstone partings in the limestone. Moreover, in the middle was a 6 ft. parting of shale grading off into the limestone above and below through streaky beds of a type well known amongst the Upper Yoredales in and around Swaledale. The bedding planes abound in wavy streaks and highly flattened lenses up to $\frac{1}{8}$ in. thick, some of which are undoubtedly chert with sponge debris ; one such lens contained the fish tooth *Pristodus falcatus* Davis. Whatever the origin, the rock is one of those oddities difficult to describe but once noted never forgotten ; good examples are plentiful in strata above the Main Limestone, recently proved in a bore east of Richmond.

Although their precise position in the sequence cannot be fixed, the rocks in the Catterick bore can be assigned without hesitation to the Carboniferous Limestone Series (Yoredales).

Turning to the Scorton bore on the east side bank of the Swale, the record here (Text-fig. 3) is entirely different. Underneath a hundred feet or so of gravel and boulder clay comes a group of red rocks, 136 feet thick consisting of sandstones, marly sandstones and sandy marls. Many of

[1] Published by permission of the Director of the Geological Survey.

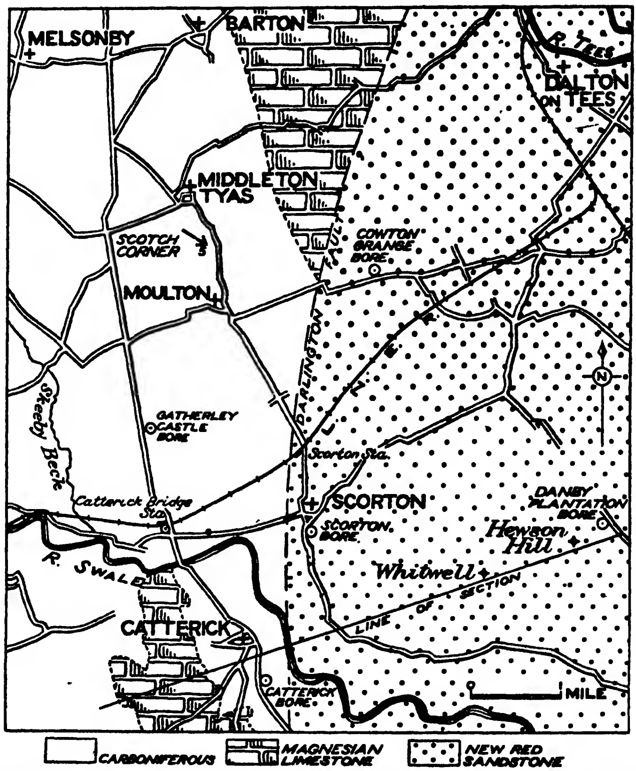
TABLE E

Epochs of movement in the North Sea Basin and neighbouring regions

Epochs of compression in geosynclinal areas	Epochs of movement in the North Sea Basin	Movements along the linear structures in the North Sea Basin	Some examples in neighbouring areas
Pleistocene epochs.	Accelerated subsidence of the bottom (influence of central graben) tilting in marginal area.	Movements in central graben, etc. (b_1, b_2, b_3).	Important faulting in Rhine-graben (a_1, a_2). Elevation of Alpine chains.
Tertiary epochs.	*Idem* (influence on geographic conditions). Accelerated subsidence and tilting in the South-East during Oligocene.	Movements along faults in the Limburg coal-district (b_3) and central graben (b_1, b_2). Details insufficient to fix different Tertiary epochs.	Attic epoch: Rejuvenated movement of salt-domes in N. Germany. Slight folding in basin of Paris. Savian epoch: Accentuation of several graben (a_1, a_2). Pyrenean epoch and Oligocene: Origin of Tertiary Rhine - graben (a_1, a_2).
Laramide epoch.	Regression at the end of the Mesozoic. Beginning of strong subsidence in North Sea basin. Origin of basin of London.	Movement along some faults in b_3 (e.g. Heerlerheide fault). Strong movements in salt-dome of Winterswijk (c_9).	Rejuvenated movement of salt domes. Origin of unconformities in basin of Paris.
Subhercynian epoch.		Movement along some faults in Limburg (b_3): e.g. fault of Benzenrade and Kunrade.	Elevation of Harz and other Variscan districts. Movements in salt-domes. Overthrusting of Osning (c_4).
Austrian epoch.			Slight movement between Albian and Cenomanian ?
Late Cimmerian epoch.	Unconformity of Lower Cretaceous on older formations. Accelerated subsidence. Warping of S.E. margin.	N.E. blocks of Limburg subsided along N.N.W–S.S.E. faults.	Origin of faults ("anticlines") in Basin of Paris, Boulonnais, Weald, Egge, Osning (c_1-c_8). Origin of basin of Munster.
Early Cimmerian epoch.	Lias (or Rhaetic) unconformably on older formations. Well defined boundary between North Sea basin and basin of North-Western Germany.	Action of Erkelenz-axis (a_3) since this epoch continuing in Mesozoic and Tertiary times.	Slight elevation of Harz. Origin of basin of Paris and basin of North-West Germany.

To face p. 244]

the marly or silty sandstones have sun-cracked shale partings and contain dark red mudstone or shale fragments. These beds rest on a 6½ ft. band of sandstone, too soft to make cores, separated from a similar rock, 12½ feet thick, by 5½ feet of well-bedded, flat-lying dolomite, quite barren of fossils. A similar but thinner dolomite, immediately beneath, caps 63 feet of red marls with massive and fibrous gypsum. The strata beneath from 326 feet down to 364½ feet are mostly arenaceous sediments with a thin bed of red marl containing ribs of dense dolomite over a 2½ ft. bed of fossiliferous dolomite with many coaly fragments. Among the fossils

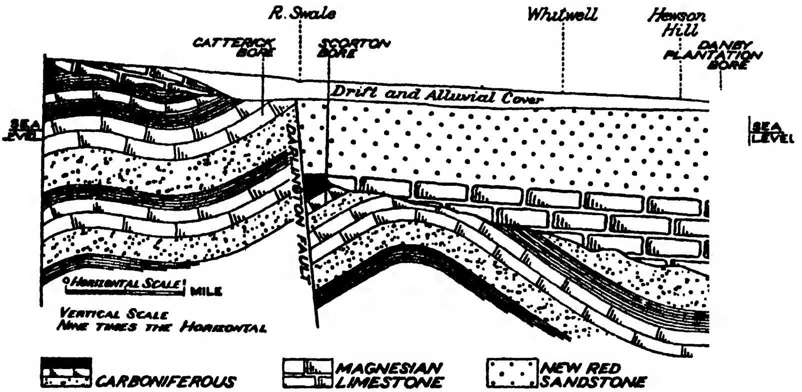


TEXT-FIG. 1.—Geological Map North and East of Catterick, Yorkshire.

Dr. Stubblefield identified the following Permian forms : Cf. *Astarte tunstallensis* King, *Bakevellia antiqua* (Münster), *Schizodus obscurus* J. Sowerby, *Naticopsis minima* (Brown), *Rissoa obtusa* (Brown), " *Turbo* " *mancuniensis* Brown, and " T." *permianus* King. The underlying sandstones are in places noticeably porous and coarse, being made up of pebbles and grit of quartz, chert, crinoid ossicles, and sponge spicules. The conglomeratic bands contain large pebbles of crinoidal and cherty limestone and chert, in a matrix often made up of loosely cemented crinoid ossicles.

Quite clearly the beds from 349½ to 364½ feet are composed of the debris from the local Carboniferous outcrops, and as they are covered by dolomite with characteristic Magnesian Limestone fossils there need be no hesitation in classifying them as basement Permian rocks.[1]

From 364½ feet down to the base of the bore at 475 feet the strata are normal Yoredale sediments, shales, crinoidal limestones, and sandstones. A large and varied assemblage of fossils from the shales included *Lingula, Orbiculoidea*, and occasional Productids, e.g. *P.* (*Dictyoclostus*) *muricatus*. Anchoring spines of *Hyalostelia smithi* were even more abundant than in the Catterick bore and were collected at intervals from 377 to 430 feet. The phosphatic worm case *Enchostoma* was not uncommon and small jaws possibly belonging to this worm were recorded by Dr. Stubblefield from 397 feet. He named these jaws *Eunicites* on the basis of Hinde, *Quart.*



TEXT-FIG. 2.—Approximate section Catterick to Danby Plantation.

Journ. Geol. Soc., lii, 1896, p. 146. From the limestone Mr. R. G. Carruthers identified a large *Campophyllum* sp. at 410 feet and a young Clisiophyllid at 446 feet. A Carboniferous Limestone (Yoredale) age for these rocks is beyond doubt and it may well be younger than the Main Limestone.

A study of the local data suggests that the red rocks of the Scorton bore should outcrop west of the village, in view of the low dip of these measures between the Scorton and Danby Plantation bores.[2] Now surface exposures at Moulton and between there and Middleton Tyas are unquestionably in the Carboniferous Limestone Series, whilst bores at Catterick Bridge station and Gatherley Castle ended in " grit ", a rock-type locally common in that formation. Moreover, in the records of the

[1] In this connection it may be mentioned that a breccia (" probably Permian ") resting on and containing fragments of purple Carboniferous sandstone was mapped by W. Gunn in the Swale, 1⅝ miles west by south of the Scorton bore, at about 200 feet above Ordnance datum.

[2] The Geology of the Country around Northallerton and Thirsk, *Mem. Geol. Surv.*, 1886, p. 4.

Geological Survey is one of a well and bore [1] at Scorton, 179 feet in all, stated to be in limestones (with flint), sandstones, fireclays, and black shale; clearly not an assemblage which can be placed in the New Red Sandstone. Presumably, therefore, there is a considerable fault between Scorton and Catterick throwing up the Carboniferous Limestone to the west, one with a northerly trend, as expressed in map and section (Text-figs 1 and 2). The direction is confirmed by two bores to the north at and west of Cowton Grange, passing into red sandstone and marls under boulder clay.

Leaving our district and passing northwards into the Tees valley and beyond, evidence is less precise although it is all in favour of a faulted Magnesian Limestone—Trias (or New Red Sandstone) boundary. The matter must perforce be treated broadly. We know that in this part of the country there is about 700 feet of " Keuper " Marl on 600 feet of " Bunter " sandstone, under which are 500 feet of " red marls ", with great masses of anhydrite at the base, resting on Magnesian Limestone. All the way across the Tees valley and past Darlington were the junction normal, this marl-anhydrite group should outcrop. Nothing but red sandstone is recorded, and that quite close to the boundary-line (in the Tees at Croft, in a bore near by, 150 feet, and more to the east at Eryholm, no less than 666 feet, the base not reached); in addition we have the " Dog and Gun " bore on the S.S.E. outskirts of Darlington, red sandstone under 96 feet of drift. There is every reason, therefore, to presume a faulted junction with the Magnesian Limestone continuing northwards from that now known round Catterick, and eventually running out to sea at West Hartlepool, where such a dislocation has long been known.

This major tectonic feature may well be termed the " Darlington Fault " and should be reckoned with in future exploration, whether in search of water or anhydrite.

It is of interest to note that the pronounced change of direction round towards the east is closely paralleled in a fault with 150 ft. throw, in the adjacent Cleveland Ironstone field at Eston Moor.

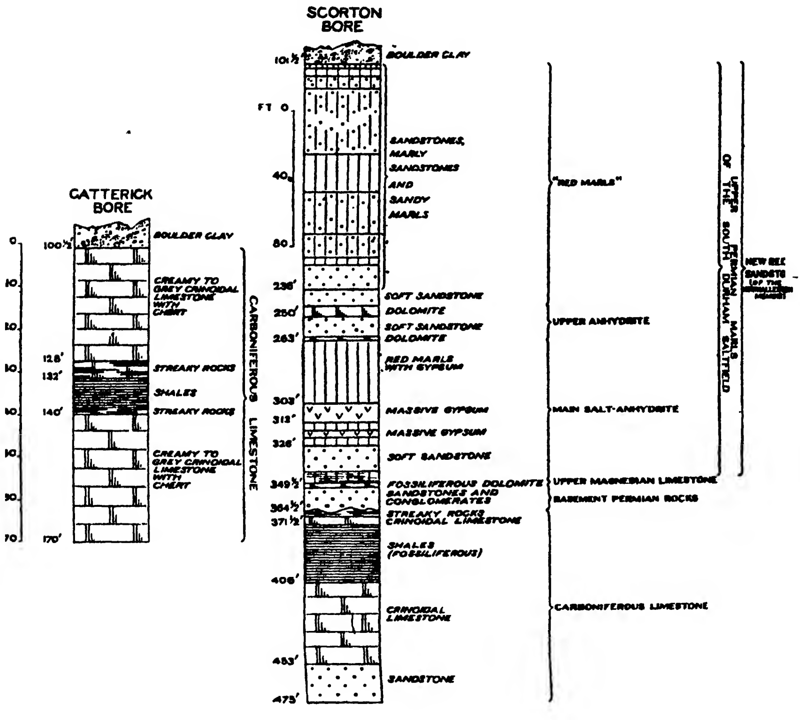
From Catterick the position seems to run S.S.E. and may perhaps reach the Coxwold-Gilling fault-system.

Interpretation of the Scorton Bore

In considering the sequence in the Scorton bore it is quite evident, as already stated, that the base of the Permian should be drawn at 364½ feet, notwithstanding an absence of the remarkable Marl Slate and dense covering limestone, so persistently present at the base of the Magnesian Limestone all along its outcrop in County Durham. To neither of these has the fossiliferous dolomite of the Scorton bore any resemblance, palaeontologically or otherwise. The red marly sandstones with mudstone fragments and sun-cracks at the top of the bore are lithologically similar to the " red marls " which overlie the salt-anhydrite deposits of the South Durham saltfield. And it is to the main salt-anhydrite beds of

[1] Unfortunately the site cannot be located but as the bore starts in rock at the bottom of the well (37½ feet deep) it cannot be on the alluvial flats west of the village: more likely it lies to the N.N.W., possibly near Scorton station.

that field that the gypsum-bearing rocks at Scorton are thought to correspond. If this is the relationship, one might reasonably look for a correlative of the "Upper Anhydrite" which Sherlock (1926, p. 24 and pl. ii) and later Hollingworth (1942, p. 143 and pl. vii) have shown to be so widespread and such a useful index to the underlying evaporites. Now the examination of several recent cores in the South Durham saltfield shows that a portion of the "Upper Anhydrite" is always a dolomite-anhydrite rock—originally it may have been entirely dolomite—with which are



TEXT-FIG. 3.—Sequences in the Catterick and Scorton bore holes.

associated thin ribs of very dense banded dolomite. Here in the Scorton bore we have, above the gypsiferous marls, a similar dense, banded unfossiliferous dolomite, albeit with a parting of soft sand-rock.

In this connection it should be remembered that Hollingworth (1942, p. 142) held that dolomite deposited over a "structurally high" area "passes outwards into anhydrite or a mixture of anhydrite and dolomite where followed out into the adjacent basins or negative areas". The suggested correlation of the highest dolomite in the Scorton bore with the "Upper Anhydrite", agrees with that contention.

The thin fossiliferous dolomite at 349½ feet is considered the sole representative of the complete sequence of the Magnesian Limestone of County Durham. It is concluded that this area was a "structural high", that it

remained above the level of the Permian sea which lapped around its flanks and which, further afield in Durham, laid down deposits amounting to 800 feet or more; hence at Scorton the extreme attenuation of the Magnesian Limestone sequence.

Here, then, for the first time, is revealed the great part played hereabouts by the Middleton Tyas fold in post-Carboniferous sedimentation. This anticlinal structure, it will be recalled, had been recognized by earlier geologists and in particular by the late Professor Kendall, as a major tectonic feature resulting from pre-Permian earth movements. But for the Scorton bore, however, it is doubtful if its great influence on Permian deposition would have been so completely disclosed for many years to come.

It seems that this attenuated representative of the Magnesian Limestone soon thickens away from the Scorton bore; it appears to be already 25 feet or more in quarries 2 miles to the W.S.W. of Catterick. Eastwards, the Danby Plantation bore, 3¼ miles from Scorton, after passing through 69 feet of surface deposits and 400 feet of "New Red Sandstone", penetrated 291 feet of Magnesian Limestone without reaching the base of the formation. Changes so abrupt as this (they are far greater north of Middlesbrough) would seem to be due to overlap (Text-fig. 2) rather than to mere attenuation or non-sequence.

In the record of the Danby Plantation bore the 400 feet of rocks above the Magnesian Limestone are classed, in the Northallerton memoir, as "New Red Sandstone", but the record does not allow of further subdivision. For that reason no attempt has been made on the map and section (Text-figs. 1 and 2) to separate the comparable rocks of the Scorton bore from the overlying red sandstone (Bunter). In the vertical section, however, they are, down to 244½ feet, correlated with the "red marls" of the South Durham saltfield and the complete sequence, down to the top of fossiliferous dolomite at 347 feet, is placed in the "Upper Permian Marls", a difficult transition group whose time-equivalent is debatable and whose upper limit is not easily defined.

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Geological Survey 1 in. Maps covering the area: Sheet 27 (Old Series 103 N.E.); Sheet 33 (Old Series 103 S.E.); Sheet 41 (Old Series 97 N.E.); Sheet 42 (Old Series 96 N.W.); Sheet 52 (Old Series 96 S.W.)

Problems of Ammonite-Nomenclature

X. The Naming of Pathological Specimens

By L. F. Spath

PATHOLOGICAL individuals or monstrosities of ammonites (kakomorphs in Buckman's terminology) have long been known and some have, rightly or wrongly, been given specific names. Indeed, they probably include a genus, namely *Nipponites*, Yabe, 1904, based on a unique specimen, the incredible tangle of which may represent only an extreme monstrosity of one of those Nostoceratids (*Didymoceras, Emperoceras*, etc.) which normally began life with a hamitid or ptychoceratid shell, then changed to a turricone and finished up with a helicoid body-chamber, often combining dextral and sinistral coiling in the same individual. A few authors have taken delight in collecting and describing such "cripples" (Engel, 1894, 1909; Wingrave, 1929); to other palaeontologists, however, they have caused nomenclatorial difficulties. Thus Crick (1901), when recording as *Ammonites ramsayanus*, Sharpe, a monstrosity in the Bath Museum, had to confess that Sharpe's type specimen certainly was deformed and he thought the Bath specimen was also a malformation. Yet he added " being unable to refer them to any other species which had hitherto been described from the Chalk, it seemed desirable to retain, at least provisionally, Sharpe's name ". Crick should have known, of course, that a specific name may be valid or invalid, but that it cannot be provisional. In other papers, however, dealing with deformed ammonites, Crick (1898, 1899, 1918) found the nomenclature less embarrassing.

When H. G. Seeley (1865) described some ammonite monstrosities from the Cambridge Greensand as new species (notably *Amm. acanthonotus* and *Amm. glossonotus*) he believed them to be normal examples (i.e. kallimorphs, Buckman). At least, he mentioned that he did not agree with S. P. Woodward who, before him, had regarded *Amm. acanthonotus* as a monstrosity of *Amm. lautus* J. Sowerby; and in the detailed description of *Amm. glossonotus* there is no hint of any deformity, but only the statement that the septa appeared to be asymmetrical. Jukes-Browne (1877), when reviewing the Cambridge Greensand ammonoids, did not express any opinion on *Amm. glossonotus*, but he disagreed with Seeley on the more extreme *Amm. acanthonotus* and declared that that species must be struck out of future lists of Cambridge fossils. At the same time, Jukes-Browne expressed the opinion that *Amm. acanthonotus* was a malformed individual of *Amm. auritus*, J. Sowerby, a guess but slightly better than S. P. Woodward's; for many years later, Jukes-Browne still included in Sowerby's late Albian species totally unrelated ammonites from the Lower Gault. Even if the types were abnormal, Seeley's forms really belonged to two new, unnamed species.

When the deformity is confined to the periphery, as in the two species just discussed, and the two sides of the ammonite are more or less symmetrical, it is possible that the abnormality would pass unheeded by the general palaeontologist. It is a kind of deformity that had already occurred in the Jurassic, for example in the genus *Kosmoceras*, and in the

Triassic, notably in *Ceratites fastigatus*, Credner, and *C. brunsvicensis*, Blanckenhorn (see Spath, 1934), and it resulted from the fusion of two rows of ventro-lateral nodes into a more or less regular median crest. Seeley's two species are thus in a different category from such monstrosities (dysmorphs of Buckman), as *Amm. paradoxus*, Stahl, or *Amm. janus*, Hauer. These malformations of the Liassic genera *Amaltheus* and *Oxynoticeras* respectively, are obvious " cripples " to every observer, simply because the two sides are so different. Undoubted monstrosities (plagiomorphs of Buckman) are also d'Orbigny's Liassic " *Turrilites* ", i.e. individuals of normal ammonite species that had left the plane spiral and become turreted. " *Turrelites* " *boblayei* is a deformed *Echioceras* as much as *E. armentale*, Dumortier sp. (1867), duly copied in Reynès (1879), though nobody has yet questioned the validity of that species. On the other hand, contrary to Pompeckj (1899), I can see no real deformity in the looped ribbing of *E. oosteri* (Dumortier).

When I redescribed *Amm. acanthonotus* and *Amm. glossonotus* in my Gault Monograph (Spath, 1928), I showed that only the holotypes of these two species were deformed but that there were many examples with similar lateral aspect yet normal periphery. There was no reason at all why Seeley's names should not be retained for the normal as well as the pathological individuals of what were, in fact, two distinct species.

Now P. Breistroffer (1940) has introduced new names for Seeley's two species. In justification of this renaming he suggested that since the species *Amm. acanthonotus* and *Amm. glossonotus* had been created for abnormal examples these names should not be applied to normal types to which, moreover, the monstrosities could be only doubtfully attached. I had myself given warning that it was uncertain whether specific identity of Seeley's poorly preserved type with the species I described as *Callihoplites glossonotus* could be claimed ; and I made it clear that I adopted the name in order to avoid giving a new name. Also, a normal type could obviously not be chosen while the holotype was still in existence. There is nothing in the International Rules of Nomenclature to support M. Breistroffer's contention ; on the contrary, the renaming is in direct violation of various Rules and Opinions, and it may be useful to discuss the different points.

First of all, Op. 93 holds that existing names are not to be changed unless there is a clear-cut necessity. It is true that the names *acanthonotus* (spine-back) and *glossonotus* (tongue-back) are descriptive of features of the monstrosities only and not of the normal types ; but specific names, once published, cannot be rejected, even by the author, because of inappropriateness, i.e. because they " indicate characters contradictory to those possessed by the animals in question " (Art. 32). It is known that in some species the original description was based on bodily parts of more than one form. Subsequent discoveries showed that the description had to be revised, but the species remained valid. Similarly the special features of the periphery peculiar to the holotypes but not the normal examples of what were taken to be the same forms do not invalidate the species.

Moreover, it is often impossible to distinguish between normal and abnormal examples in ammonites, especially in regard to irregularities in the ornament. In his Gault Monograph the writer had occasion repeatedly

to direct attention to slightly malformed examples that connected the normal ammonites with the more extreme monstrosities. There are other cases of abnormality in ammonites. In the Valanginian *Platylenticeras heteropleurum* (Neumayr and Uhlig) every specimen has an asymmetrical suture-line ; that is to say, truly normal examples are unknown. It has been claimed that the thin, sharp-backed species just mentioned was abnormal because it lived like flat-fish, constantly on its side, instead of being adapted, like other oxynote shells, for rapidly cutting through the water. In this connection it may be significant that asymmetry is rare in the inflated, round-backed *Aspidoceras* (Vadasz, 1909 ; Spath, 1931), which must have led a *Nautilus*-like existence (see Spath, 1919).

Again, the triangular coiling of a *Clymenia* (*C. paradoxa*, Münster) may have seemed as abnormal as the elliptical shape of a Carboniferous goniatite (*Nautellipsites*) until a sufficiency of material proved that the first was indeed normal but the second accidental (allomorph in Buckman) and only due to deformation in the rock. Yet this does not affect the nomenclature. Nomenclatorial rules were framed to ensure stability, and in the case of rival claims, objectivity ; and as Op. 107 states, in cases of doubt it is always advisable to choose the solution that upsets as little as possible existing nomenclature.

The species also are not invalidated through being hypothetical (Ops. 2, 118) ; and if it be claimed that Seeley's original figures or descriptions were inadequate, this applies to all of his Cambridge Greensand forms, normal or deformed. The validity of a name is a question generally decided by the reviser, and the writer's redescription of Seeley's species in 1928 not only established their nomenclatorial status but first made them generally known. It is to be assumed that the reviser who has before him the types and other available material is in a position to determine the species correctly. According to Opinion 19 the general principle is that an identification has to be accepted until it is proved to be incorrect. For example, it can easily be shown that S. Buckman misidentified *Leioceras opalinum* (Reinecke) because its radial line agrees with that given by Buckman for his " *Cypholioceras opaliniforme* " of an earlier horizon, but not with that of the later species attributed by him to *L. opalinum*. In the case of malformations such direct proof is generally impossible and interpretation becomes subjective. Thus it may be possible to suggest, with Engel, that the malformations of *Amaltheus* that have been figured as *Amm. paradoxus* are mostly pathological individuals of *Amaltheus gibbosus* (Quenstedt) ; and Buckman (1904) was probably right in assigning the malformation of " *Lioceras concavum* " he had figured in 1888, to his later species *Graphoceras stigmosum*. But the doubtful " cripple " Buckman (1920) figured as *Pseudolioceras erratum* (Simpson) is neither a valid species nor referable, with certainty, to any known genus. It would also be very rash to attach to distinct species of *Schloenbachia* such malformations as *Amm. cinctus*, Mantell, *Amm. vectensis* and *Amm. ramsayanus*, Sharpe. These are not so frequent as the monstrosities of the Cambridge Greensand and transitions are as yet lacking.

M. Breistroffer took as type of his renamed *Callihoplites acanthonotus* a Cambridge Greensand specimen figured by the writer, and he does not question the identification any more than in the similar case of *C.*

glossonotus, though here the type is styled provisional. The Rules recognize no provisional types; a specimen designated as the type of a species cannot be replaced by a " holotype " to be figured at some future date.

There has been but little nomenclatorial difficulty with ammonites in which the adult body-chamber is constantly modified. They have also been called abnormal, but wrongly, for every individual of a given species shows identical modification. This may consist of a more or less abrupt change to incoiling or uncoiling of the outer whorls, the development of scaphitoid or regularly geniculate body-chambers, the loss of lateral lappets in the adult, or, conversely, the acquisition of such lappets at the final aperture only, the appearance of a sharp keel in the adult, or the loss of an early keel on the outer whorls, and so forth. Many of these modified forms have been named, specifically and generically, some because they were believed to represent sexual differences. The names have come to stay, e.g. *Cadomites* and *Normannites*, referred to in No. IX of the present series of articles, simply because they were needed and despite the fact that the alleged sexual dimorphism is now disproved. When a modified outer whorl occurs in an isolated individual of a form that does not normally modify its body-chamber we speak of malformation again, such as a Liassic *Lytoceras* with loose, last whorl (Vadasz, 1908) or a scaphitoid *Promicroceras* (Spath, 1926). More easily recognizable as monstrosities, however, are those rare examples of ammonites in which the body-chamber is accidentally and quite asymmetrically deformed by some injury, received during life. Few names have been bestowed on " cripples " of that kind (e.g. Quenstedt, 1883) since the earlier whorls generally reveal the normal characters of the species; *Caenisites*, Buckman (1925), based on a deformed example of *Amm. plotti*, Reynès, was, however, given generic rank.

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Nick Points and the Curve of Water Erosion

By. W. V. Lewis

INCREASING attention has been paid in recent years to the reconstruction and interpretation of stream profiles. It might therefore be well to examine a little more closely the way in which the curve of water erosion and the polycyclic valleys are produced. In this paper these problems are considered in the light of some preliminary experimental work recently described in this Magazine (1).

Literature.—In a most illuminating early statement of river action Gilbert (2) asserted that the capacity of a stream to do work increases with discharge in more than simple proportion. Thus, if two tributaries unite, the combined stream can cut a flatter gradient than can either tributary singly. A concave curve will therefore result as the discharge of the stream increases steadily from source to mouth : or, in Gilbert's words, " declivity bears an inverse relationship to quantity of water." O. T. Jones (3) followed a similar argument in a paper which, both in accuracy of field measurement and in discussion of fundamentals, set a high standard. On this assumption one might expect a sudden flattening of gradient at each important junction, and Jones suggested that this does occur.

Implicit in these arguments is the fundamental factor of base level. If this is ignored Challinor (4) shows that paradoxical conclusions result. Starting with Gilbert's assertion above, he argued that if two fully loaded tributaries, with similar gradients to that of the combined stream, unite the main stream is no longer fully loaded, and so is capable of eroding. Erosion should therefore increase downstream as discharge increases, and so the curve of erosion should be convex upwards ! Granting the presence of a base level, however, even if increased erosion does occur below a junction, this only serves to reduce the gradient further downstream, as was repeatedly demonstrated in the experiments in the stream trough of the Physiographical Laboratory at Cambridge (1). Also the increase of slope below the junction might recede up both tributaries.

Lake's explanation (5) of the curve of water erosion is different. He attributed the curve to the slight erosion both near the source, where a stream has little load, and near the mouth, where it is fully loaded, whereas in the mid parts of its course it actively picks up load. It thus lowers the middle of its course most rapidly and so tends to produce a concave curve. The importance of the degree to which a river is loaded in times of flood—the only times that really matter—cannot be overemphasized. For wherever a river is loaded to capacity—and flooded rivers are always striving to pick up their maximum load—down-cutting ceases irrespective of whether a base level exists or not. But the repeated curves of water erosion resulting where a river crosses an alternating series of hard and soft outcrops present some difficulties on this explanation.

Wooldridge and Morgan (6) rightly stressed both base level and increase of discharge in their explanation. They attributed the relatively small amount of down-cutting in the upper reaches to small discharge, and in the lower reaches to the nearness to base level.

A recent contribution to the problem by Green (7) seems, in part, likely to give rise to confusion. The matching of a mathematical formula with a portion of a stream profile above a nick point by purely empirical means, and then extrapolating in order to estimate past sea levels, is of value in the absence of more direct geomorphological evidence. It is of value also in checking and amplifying data, but long extrapolation should be used alone with great caution. Austin Miller (8) has issued a timely warning on this point. Green has, perhaps, gone too far in deducing the possible evolution of a river profile from such an empirical formula. This has led in one case to a result that can hardly be taken as typical.

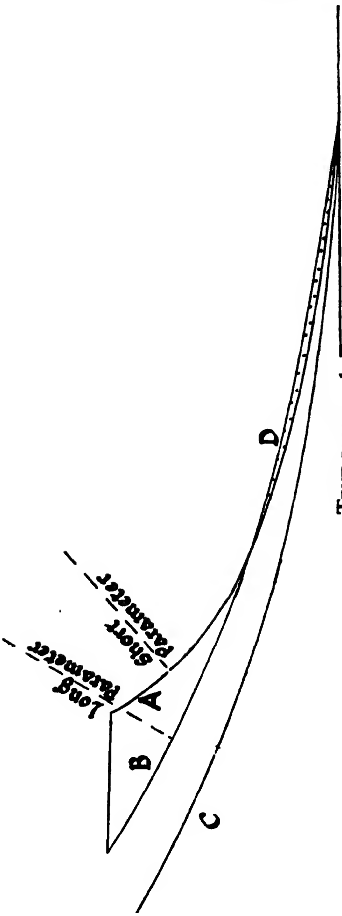
Green (9) matched the curves of the Mole and other rivers with that represented by the formula $y = a - k \log(p - x)$, where "y" is the height in feet above ordnance datum at a distance "x" miles from the river's mouth, and "a" and "p" are arbitrary constants. Special significance is attached to the parameter "k" which, like the other constants, is chosen so as to fit the given river profile ; but the parameter is defined as being proportional to the greatest curvature, whereas it is proportional to the *radius* of curvature where the curve is sharpest. In the appendix to Green's paper Jeffreys shows that the minimum radius of curvature $= 1 \cdot 128 \ldots k$. Green finds that in any one river the parameters of terraces tend to increase with the length of the terrace, from which he concludes that river profile *A* (Text-fig. 1), with a short parameter, might develop into profile *B* with a longer parameter, thus aggrading slightly its lower course.

A consideration of first principles suggests that this is not the normal course of events. For the river at stage *A*, in flowing down the relatively steep headwater slope, might be expected to reach the neighbourhood of *D* with a larger load per unit of discharge than when at stage *B*, with a much reduced slope. If this were so the laboratory experiments (1) indicate that the river would require a steeper slope from *D* to the sea at stage *A* than at stage *B*, the reverse of the conditions envisaged by Green. In fact a curve such as that through *C* would probably result. This curve might well have a long parameter similar to *B*, but it follows a gentler gradient than either curves *A* or *B*.

It seems then that some clarification of the factors influencing the curve of water erosion is needed, a clarification which should aid the further development of the theory of polycyclic valley profiles. A brief but admirable criticism of methods of reconstructing stream profiles by D. W. Johnson (10), and an equally admirable reply by Baulig (11), both illustrated the need for more fundamental knowledge of river action, in order to handle and interpret these reconstructions with greater facility and confidence.

Effect of Increase in Discharge.—Some preliminary laboratory experiments bearing on these matters were carried out at Cambridge (1). In the first experiment sand was fed in at the head of a miniature stream and the changes in profile recorded. With the notable exception of the start of the profile, it seemed that the straight line, rather than the concave curve, was the ultimate goal of the little stream. But in these experiments mass and calibre of load, and discharge of the stream were kept constant. In the second experiment the volume of the stream was increased by

tributaries at two points, and the final profiles showed distinct if erratic tendencies to form a concave curve. This section of the profile was not graded as it was being continuously eroded. The result of the increased erosion below the tributaries led to a local steepening of gradient, and so to greater erosion just upstream, but inevitably reduced the gradient on the next downstream section. This is merely a single example, but it supports authoritative views, and suggests that the factor of increasing discharge is of fundamental importance. The long profiles of the headwater streams of the River Noe in the Vale of Edale (12), which were surveyed during a Geographical Field Meeting also supported this conclusion. The relatively small changes of gradient accompanying the countless distributaries as they divide and reunite in the outwash plains of South-East Iceland (13), warn one, however, against giving too great weight to this factor alone. The repeated curves of water erosion due to hard outcrops, also suggest that some factors other than increase of volume are of prime importance.



TEXT-FIGURE 1.

Effect of Comminution of Load.—In the laboratory work the first experiment showed, apart from an initial short curved section, that a uniform gradient was being formed. The second experiment, with three tributaries, showed stronger but not unequivocal tendencies to form a concave curve. The most significant departure from this curve was across the sand flats of the delta where the gradient was markedly steeper than that further upstream. We were thus led to consider carefully any important differences between the conditions for the experimental streams and for full-scale rivers. It seemed that the one important characteristic of rivers which did not apply to the experiments was that of the gradual reduction in the calibre of the load as the boulders wear down to pebbles, pebbles to gravel, etc., and the proportion of sand, silt, and clay increases.

It has not yet been possible to arrange for the gradual reduction of load calibre in the experiments, but this would not seem to present insuperable difficulties for future work. The experimental work of Owens (14) and Hjulström (15) indicates the far greater ease with which streams can carry fine than coarse material, and Gilbert (16) expressed himself in no uncertain terms on this matter. It is probably a fundamental

factor in the development of the curve of water erosion, and one to which insufficient attention seems to have been given.

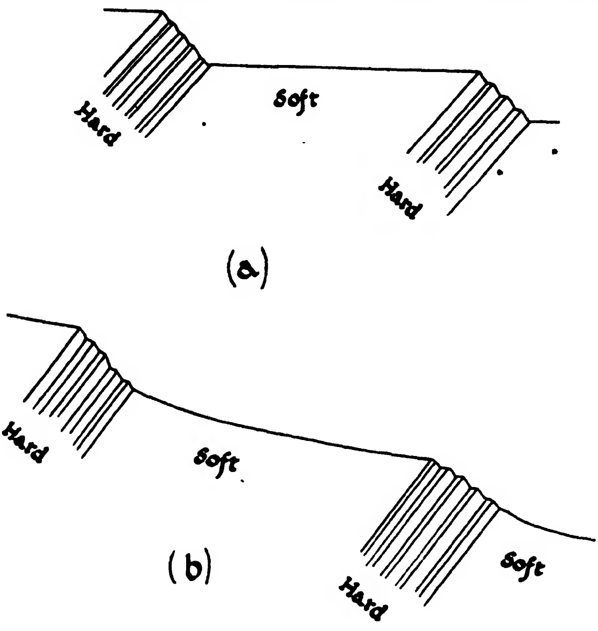
Variations of discharge still further increase the efficacy of streams as carriers of fine as compared with coarse material. The discharge of streams the world over varies considerably from time to time (17), and although some of these variations are smoothed out in the larger rivers, they, too, continually vary in discharge. With a mountain torrent the coarsest material can only be moved during severe floods, but silt and sand, and even fine gravel, can still be carried at the normal or even low water stages. Thus stream energy during far the greater part of the year is useless to transport boulders, large pebbles, etc., but can readily be harnessed to carry the finer fractions. In fact the finer material is so quickly removed that these mountain streams are noted for the crystal clearness of their waters. Only in occasional quiet pools is the finer material preserved. That it bulks large in the load of even swift head-water streams is shown by the composition of deltas in artificial ponds and reservoirs in hilly districts.

This selective action of streams leads to a washing away downstream of the finer material and to a concentration of coarse material in the upper reaches. These boulders and pebbles can only be removed by the relatively small head streams, even in times of flood, if the gradient is steep. Nearer the sea where, due both to this selective transport and to wear, the load is o' finer calibre, the same weight of material per unit discharge can be carried down a much diminished gradient. Large rivers are usually more turbid than mountain streams, and whilst carrying vastly more material during floods, yet carry some load during the far longer periods of normal flow. Thus it seems that a large river, with its smaller fluctuations of discharge and with a load of far finer calibre, is a more efficient agent of transport than a mountain torrent ; being more efficient it can carry its load to the sea down a greatly reduced slope. This factor of load calibre functions uniformly irrespective of sudden accessions of volume at junctions—or of loss of volume in dry regions—it is the one factor that acts slowly and progressively from source to mouth, and so would seem well fitted to help in accounting for the sweeping concave curve of erosion.

Lastly this factor seems best able to account for the repetitions of the concave curve as a river crosses alternately hard and soft outcrops. For erosion down the steep gradient at each hard outcrop would usually provide a new though not abundant source of coarse material, and so a fresh curve would tend to start which would flatten out downstream as the material wore down. Without this gradual reduction in calibre, and without any increase of discharge, the resulting profile would probably resemble that in Text-fig. 2A, whereas with it the more typical curves of Text-fig. 2B might be expected to result. In this argument it must be noted that the river is not graded where it crosses the hard strata, so the repeated curves are not fully graded curves.

Effect of Change from Erosion to Transport.—The first experiment in which mass and calibre of load and discharge were kept constant, and no base level was introduced, might appear to have been designed so as not to reproduce the curve of water erosion. Yet, just at the beginning

of the stream, a markedly concave curve was one of the most consistent features of the experiment. This was attributed to the greater velocity—and so the steeper gradient—required for the stream to pick up its load, compared with that required merely to keep the sand moving once it had been picked up. Hjulström (15) shows how much greater velocities are required for erosion than for transportation even with unconsolidated bed material. When much of the load has to be chiselled out of the solid rock far greater differences of velocity, and so of gradient, must exist between the reaches where erosion predominates and those where transport



Text-figure 2.

predominates. Thus we might expect, for this reason alone, far steeper gradients in the upper than in the lower reaches of a river. Further, anywhere in a river's course where simple transport is succeeded downstream by erosion-cum-transport, a marked steepening of gradient—a minor nick point—must occur.

The Development of the Curve of Water Erosion.—Let us consider an ideal case to help in summing up these remarks on the curve of water erosion. Let us assume: (i) that a uniformly sloping land surface (Text-fig. 3) meets the sea at *B*; (ii) that the strata are reasonably uniform throughout; (iii) that the water-table *EC* intersects the surface at *C*; (iv) that the stream gains volume at a uniform rate as it flows from *C* to *B*; (v) that the slope and discharge are such that the stream can accomplish some erosion at its source; (vi) that the sea removes material from *B* as quickly as it is brought down by the river.

Downstream, as volume increases, the stream's power to erode and transport increases at a faster rate than the volume. Also some of the

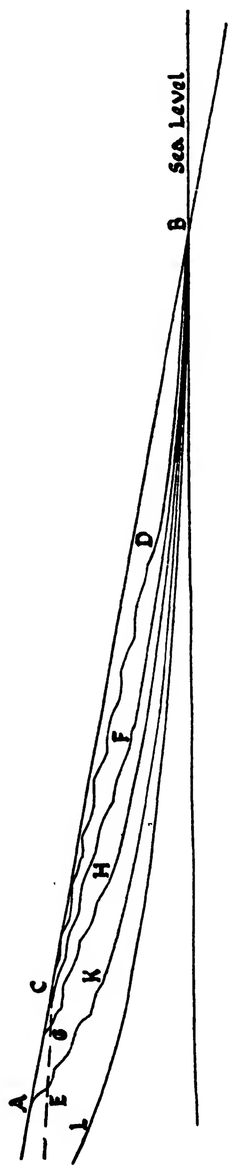
material gained near the source wears as it travels downstream, and is more easily carried, so that still more of the river's energy becomes available for erosion. Thus a curve *CD*, perhaps slightly convex upwards in the first instance, is produced. This stretch is subjected to erosion, however, so the details of the slope are determined mainly by the nature of the rock outcropping at the surface. The curve *CD* is therefore represented by a slightly zigzag line to draw attention to these factors which would certainly modify, and might well over-rule, any tendency to form a convex or waxing (18) curve. At *D*, however, the stream first feels the effect of the base level. From *D* to *B* the curve is such that the river can just carry its solid load to the sea—i.e. it is graded. This curve flattens downstream, sea level acting as a hinge, owing both to continued comminution of the load and to increase in volume. Thus it is the influence of a base level of erosion that turns what might develop into a curve convex upwards, into the familiar concave curve.

Continued erosion results in the graded portion retreating upstream to F, for erosion must always end at the point from which the slope downstream is just sufficient to carry the river's solid load to the sea. The source would also recede slightly, tapping the water-table a little further back along the line *CE*. As this recession would probably be less than that of point *F*, the slope *CF* would be steeper and shorter than *CD*. Erosion and adjustment continues to the stage *GHB* by which time a steep slope—representing the angle of rest of the material—develops above the source *G*, down which material moves due to weathering and soil creep. *EKB* represents a still later stage. The steep slope *AE* above the source has increased in length as the source recedes into the mountainside where the water-table is deeper (19). Owing to the more rapid drainage by the river, and to the decrease in the amount of high ground, the water-table (and so the source) would, in all probability, have fallen below the original level *E*.

A further change would probably take place. The hard angle at *A* would tend to become rounded. For soil creep down the steep slope *AE* would remove superficial material from the neighbourhood of *A* quicker than it would be supplied down the gentler slope above *A*. Thus the bedrock at *A* would always tend to be exposed and to suffer severe weathering. Frost shattering would be particularly effective at moderate altitudes in temperate latitudes. The consequent lowering at this point would cause the slopes above *A* to increase, and those below to decrease, thus leading to a rounding of the angle. This rounded form would be fairly stable, for it would give rise to a more uniform rate of soil creep which would allow an unbroken mantle of waste to cover and help preserve the underlying rock. Wood, in a most illuminating paper on hill slopes (18), perhaps over-simplifies this matter by attributing the rounding only to the weathering of the angle on two sides.

The continued existence of the re-entrant angle at *E* is due to the ability of the stream to remove the waste supplied from above down a gentler slope than the processes of soil creep are able to do, and still have energy available for down-cutting. Thus a considerable proportion of the energy of the headwaters is used in headward recession. This naturally tends to retard the purely vertical down-cutting of these head-

streams and still further encourages the development of the concave curve of erosion in the stream profile as a whole.



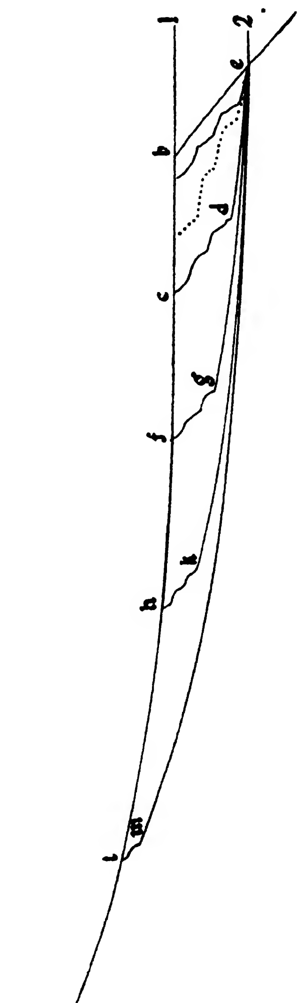
TEXT-FIGURE 3.—SUCCESSIVE STAGES IN EVOLUTION OF THE CURVE OF WATER EROSION.

Each curve is drawn below the preceding one because when the river in, say, the stage *EKB*, is at a distance *HB* from the mouth, the calibre of the load is finer, and perhaps the discharge is greater, than when at *H* in the stage *GHB*. This finer load can be carried to the sea down a gentler slope. The calibre of the load at *K* in stage *EKB* would be similar to that at *H* in stage *GHB* if *EK* approximately equals *GH*. When eventually the amount of high ground is greatly diminished the graded reach will recede further inland, but probably never to the source, for there will always tend to be a stretch along which the load is being picked up, and which must always remain distinctly steeper than the reaches next downstream, where transport predominates. As the cycle of erosion continues the smaller mass and calibre of the load will enable it to be carried to the sea down an ever more gentle gradient, leading to the stage *LB*, only partly shown, by which time the stream will be passing from maturity into old age. The later stages represented in Text-fig. 3 would require a far greater time interval for their respective development than would the earlier profiles.

Suppose the slope, discharge, and resistance of strata were such that the stream was unable to erode at its source. Then erosion would have to await increased power due to increased discharge, and would begin further down stream. Supposing discharge increased solely by means of a few tributaries, then one of the first results might well be the forming of a nick at each junction. These would almost certainly recede up each tributary, whether or not a small change of slope would remain at the junctions would seem largely to depend on whether the flood waves down each tributary habitually met at the junction, or whether they arrived there out of phase. Further field evidence is required on this matter.

The Survival of Nick Points.—Many attempts were made in the laboratory

to cause rejuvenation by lowering the water level at the foot of the stream trough. Also in the second experiment (p. 257 above) an artificial nick point was subjected to erosion and the stages in its retreat were recorded. This experiment was repeated more than once, but without the profiles being accurately measured each time. These examples revealed many points which might help us to understand the problem of the survival of nick points ; a problem which Baulig (20) admits has not yet been solved.



TEXT-FIGURE 4.—SUCCESSIVE STAGES IN THE RECESSION OF A NICK POINT.

The mixture of sand and mud used in the second experiment was resistant compared with pure sand, for sand alone lacks both the cohesion of finer particles and the inertia of coarser ones. With this and other experiments and observations in mind, some attempt can be made to reconstruct the probable sequence of events associated with a nick point.

Let *a b* (Text-fig. 4) represent the profile adjusted to sea-level 1. When the sea falls to level 2 and rejuvenation proceeds, let us assume that the sea carries away the detritus from the mouth of the river as quickly as it is brought there by the stream. The stream in flowing down slope *b e* is able to erode, but owing to the resistance of the bedrock let us assume that the stream reaches the sea still not fully loaded. Many factors might influence the rate of erosion down the slope *b e*. The disparity between actual and potential flood load—and so the flood velocity of the stream—is greatest near *b*. Thus the most likely course of events is for erosion to be most severe at the head of the rejuvenated reach. The resulting upstream recession of this section accompanied by the slower recession of the remainder of the rejuvenated reach would lead to a stage represented by the dotted line. Let us, for simplicity, assume that the rate of erosion is constant throughout the reach *b e*, that the disparity between the actual and potential load near *b* is balanced by the extra abrasion of the

more abundant coarse material near *e*. The steep slope will then recede upstream maintaining approximately the same gradient. In either case details, if not the entire nature of the slope, will depend on the jointing and bedding of the underlying rock. Thus, as in the corresponding portions of Text-fig. 3, the profile is represented conventionally by a zigzag line.

As soon as section *b e* recedes a small distance inland the slope must become reduced near the mouth to one which is just sufficient for the stream to carry its load to the sea, i.e. this portion of the stream is graded. This graded reach is steeper than the corresponding reach at sea-level 1, owing to the extra load derived from the steep section immediately upstream and which has to be carried seawards. This composite slope continues to retreat to the stage *c d e*, the ungraded portion *c d* getting gradually shorter in consequence of *d e* being steeper than *c b*. But slope *d e* also gets gentler because the load at *d* is less as a result of this slight shortening of the steep slope. Also *d e* becomes slightly concave owing both to the wearing down of the newly derived coarse material, and, in most cases, to increased discharge. Subsequent stages *f g e*, *h k e*, *l m e* all show the steep slope getting shorter, and the flatter graded reach growing longer and more concave. The steep slope *l m* is unlikely to disappear entirely until it nearly reaches the source. Nor can the slope downstream from *m* fail to be steeper than that of profile *a b* the same distance from its source. For the stream reaches *l* with a load gathered in section *a l*, which it can carry to the sea down a slope *l b*, but it now has a steeper slope downstream *l e*, and so can pick up more material as soon as it feels the effect of this increase of slope. The reach along which erosion occurs has, for the reasons given above, to be maintained distinctly steeper than that for transport alone. Having picked up this material from *l* to *m*, the slope seawards must remain steeper than that of profile *l b*, in order to carry this additional load.

In practice the change of function from erosion to transport—and so the angle between *c d* and *d e*, etc.—would not be as sharp, and the rock outcrops would probably gradually disappear beneath the debris in the graded stretch. Some of these characteristics of rejuvenated profiles have been noted by Baulig (11).

The river profile above the nick point has been kept constant for simplicity, but in reality it would continue to pass through the later stages of the cycle of river erosion. This would probably cause no fundamental departure from the sequence of events outlined above.

Thus the nick point might be expected to persist even though the height of the step gets gradually less in the course of upstream recession. The fact that slopes *c d*, *f g*, etc., would probably not, in practice, remain parallel to *b e*, in no way invalidates the main trend of this argument. Nor would the sequence of events be materially altered if the initial fall in sea-level were less, or if the slope *b e* were gentler. The presence of a delta building out from *e* would cause the amplitude of the steps, and consequently the difference between the gradients above and below the steps to be less than in the example cited, and eventually might help the nick-point to disappear without having reached the headwaters. For, if a delta formed, each successive slope from *d*, *g*, *k*, and *m* respectively

would pass over *e* at a higher level, in order to maintain the necessary gradient to the ever-advancing mouth. The nick-point would disappear if a stage could be reached in which this slope coincided with the original profile *a b*.

Nick points not due to Rejuvenation.—Supposing the profile *a f g e* resulted not from a lowering of sea-level, but from the presence of a resistant outcrop confined to the section *f g*, there seems nothing to suggest that the profile would be materially different from that shown for this stage. Supposing further that this outcrop consisted of a dyke or localized hard bed parallel to *f g*. If the river wore through this bed there seems to be no reason for suggesting that the subsequent development should differ greatly from that given above.

The final profile in the second laboratory experiment showed no less than six breaks of slope, and the streams at Edale showed a similar number. If such breaks of slope occurred on a river profile, an over-zealous advocate might attribute them to changes of sea-level. In the experiment four were associated with the increased erosion below tributaries, and all formed in well-mixed material. The lowest occurred at the change from the sand and mud mixture to the incoherent sand of the delta. At Edale some but not all were associated with junctions, and again the material, particularly the drift, was reasonably uniform.

Variations in the jointing and hardness of rock, often within the same geological beds, are the most frequent cause of breaks of slope ; also many steps can be attributed to the work of long departed valley glaciers, and others—which might even appear to correlate—to systematic river capture (21). Perhaps most misleading of all would be the steps formed where a river, for one or more of a multitude of reasons, changes its function from one of transport to one of erosion, and downstream reverts to transport once more. It might therefore be difficult to distinguish nick-points due to changes of sea level from those caused otherwise. It is, of course, essential to compare the profiles of neighbouring streams as has been done with the Weald rivers (22), but if there is a super-abundance of nick-points in each stream the chances of fortuitous correlation are high.

In conclusion I wish to express my indebtedness to Mr. Philip Lake by whom it was my good fortune to be introduced to the problems of river action, to Mr. J. A. Steers for helpful criticisms of this paper, as also to the Rev. D. Britt-Compton, and finally to Mrs. R. W. Wood for kindly drawing the diagrams.

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On the Chloride Waters of Great Britain [1]

By W. Anderson

FORMERLY there were several surface brine springs in the North-East Coalfield; to-day there are none. From the many accounts of their occurrence nothing has been learned of their exact position, and very little of the composition of their waters. The earliest record, made in 1684, described the Butterby spring (Todd, 1684), and then at various times during the next two centuries brine springs at Framwellgate, Lumley, Birtley, Walker, Wallsend, Hebburn, and Jarrow were noted. In particular the Birtley salt spring is often mentioned, and on the 6-in. Ordnance map, Durham No. 13, 1862 edition, it is sited to the south-east of the village. Although no record has been found there must have been either a brine spring [2] or well at Gateshead, for the name of the present-day suburb, Saltwell, is very old, and brine springs are still active in the coal workings of that area.

The localities of the above springs, with the exception of Butterby, lie along two lines which meet almost at right angles in the Saltwell area. Birtley and Lumley are south by east from Saltwell at distances of 4 and 8 miles respectively: the remaining places are east by north from Saltwell, Jarrow, 6 miles away, being the most remote area. Framwellgate and Butterby are, respectively, 7 and 10 miles due south of Birtley. The above two lines coincide with the directions of the faulting of the district as proved by mining, and indeed—again with exception of Butterby—none of the brine spring areas is free from these fractures. Some connection with the faults is therefore probable (the Birtley member is mapped at the junction of two such dislocations). As for the Butterby spring it may have been at the outcrop of the basalt dyke which crosses the northern part of the river haugh in the same direction as the easterly-trending faults; Todd stated that the spring bubbled up from the bed of the River Wear and was so salty that the river water was rendered brackish for more than 100 yards downstream (Todd, 1684).

In 1794 the Birtley spring was described as "salter than the sea" and "yielding 26,000 gallons per day" (De Rance, 1886). These waters must have been analysed, for in 1857—from local knowledge it seems that the spring ceased to flow soon afterwards—Glover wrote: "I know abundance of brine springs in England, and especially the brine springs about Birtley, in the County of Durham, from which bromine could be obtained as readily as from the waters of Kreuznach" (Glover, 1857). The Walker spring, between 1790 and 1799, was used in the manufacture of alkali; an account of this reads: "It was upon this brine that the experiments of Mr. Losh and the Earl of Dundonald were first commenced and were continued until the repeal of the duties on salt." An analysis of its water gives dissolved salts amounting to 43 parts per 1,000, consisting of 32 parts sodium chloride, 10 parts calcium chloride, and the remaining part comprised of magnesium chloride and the carbonates of calcium and iron (Kingzett, 1877).

[1] Published by permission of the Director of the Geological Survey of Great Britain.

[2] Many of the "spa-wells" of the North Country are surface springs.

Underground brine springs have been encountered during mining operations in the North-East Coalfield for more than a century. The earliest record is of those in the collieries at Hebburn, Wallsend, and Percy Main (Hutton, 1831). They were also found in the Felling, St. Lawrence, and Harton mines (Wood, 1862). All these workings are between Gateshead and the mouth of the Tyne, and lie along the line, running east by north from Saltwell, which marked the location of the surface brine springs. Salt waters were also met in the Birtley, Lambton, and Framwellgate collieries (Daglish, 1863). In spite of their long

TABLE I

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ba	—	—	—	1·06	—	·71	1·18	·34
Ca	36·11	11·09	7·95	8·91	9·52	12·44	7·45	14·06
Mg	trace	trace	1·22	·93	·91	·01	·53	·02
Na	trace	27·23	28·62	27·38	26·86	25·31	29·68	23·73
CO_3	—	—	—	—	·13	·04	trace	·02
SO_4	—	—	·89	—	1·43	—	—	—
Cl	63·89	61·68	61·24	61·66	60·62	61·49	61·16	61·83
Fe	—	—	·08	—	·51	—	—	—
Li	—	—	—	·06	·02	—	—	—
Salinity	10·572	9·392	5·769	8·518	7·818	16·134	14·839	14·607

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Ba	·94	1·32	·74	1·59	3·31	2·41	3·43	2·26
Ca	7·08	8·20	7·21	4·95	5·50	10·82	6·23	6·39
Mg	·05	·62	·77	1·07	1·38	·81	·81	·30
Na	30·37	28·67	29·72	31·31	29·24	24·35	29·26	30·57
CO_3	trace	·20	—	·10	·50	·26	·51	·68
SO_4	—	—	—	—	—	—	·02	·15
Cl	61·56	60·80	60·70	60·98	60·07	61·35	59·74	59·65
Fe	trace	·19	—	—	—	—	—	—
Br	—	—	·86	—	—	—	—	—
Salinity	13·766	7·738	6·921	4·727	4·155	2·848	2·542	1·894

(1) Wallsend Colliery Spring in 1842 (Wood, 1862).
(2) Wallsend Colliery Spring in 1848 (Wood, 1862).
(3) St. Lawrence Colliery Spring (Wood, 1862).
(4) Redheugh Colliery Spring (Bedson, 1887).
(5) Wardley Colliery Spring (Bedson, 1887).
(6) to (16) Other Springs in the North-East Coalfield.

history it appears that analyses of only five underground brines have been published, and these in two accounts without any comment upon the origin or peculiar composition of the waters (Daglish, 1863, and Bedson, 1887). These analyses, recalculated to a percentage composition, are given in Table I. It will be noted that the dissolved salts in three of the waters are entirely chlorides, and mainly so in the other two, and that all five brines have a salinity twice to thrice that of the present ocean. Though it had long been known that a deposit of barium sulphate was formed when several of the brines were mixed with mine-waters from higher seams, Bedson, in 1887, was first in demonstrating that the barium was present as the chloride in the brines (Richardson, 1863, Dunn, 1877, Clowes, 1899).

Interest in the presence of barium in certain mine-waters of the North-East Coalfield started the present investigation. Whereas the majority of colliery companies readily presented analyses of their mine-waters, many of them had reason to withhold publication as to the exact locations

TABLE II

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Ba	·72	·1	1·0	1·5	—	—	—	—
Ca	7·3	3·6	4·1	10·3	6·7	2·5	2·3	3·2
Mg	3·2	1·5	1·0	1·7	·1	1·4	·8	1·2
Na	23·7	32·9	32·7	24·5	31·8	34·5	35·6	33·7
CO_3	1·2	1·0	·3	—	—	·5	1·8	·3
SO_4	·02	—	—	—	—	·4	·2	·04
Cl	61·0	60·5	60·8	62·0	61·2	60·5	59·4	61·1
Fe	2·4	—	·1	—	—	—	—	—
Br	·06	·1	—	trace	·2	·2	—	—
Li	—	—	—	·05	—	—	—	—
K	·4	·3	—	—	—	—	—	·5
Salinity	0·656	0·900	2·456	0·427	6·536	2·229	1·081	3·043

	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)
Ca	11·0	11·7	2·6	24·8	7·2	17·4	20·3	21·4
Mg	·8	3·9	1·3	·4	1·6	—	·6	—
Na	24·8	20·7	34·5	11·6	28·8	20·2	16·0	15·9
CO_3	·2	·9	—	·1	1·1	—	1·0	1·1
SO_4	·1	·05	—	·05	2·8	1·1	2·5	1·4
Cl	61·5	62·6	61·6	62·9	58·5	61·3	59·0	60·2
Fe	·2	·2	—	·07	—	—	—	—
Br	trace	—	—	trace	—	—	·6	—
Li	—	—	—	trace	—	—	—	—
K	1·4	—	—	·09	—	—	—	—
Salinity	2·114	1·722	5·130	1·347	0·985	0·833	0·938	0·423

(A) Harrogate (Thorpe, 1881), p. 502.
(B) Thorp Arch, Wetherby (Thorpe, 1881), p. 516.
(C) Ilkeston, Derbyshire (White, 1899).
(D) Llangammarch (Luke, 1919), p. 146.
(E) Moira Main Colliery, Leicester (De Rance, 1886), p. 66.
(F) Woodhall Spa, Lincolnshire (Barnes, 1895), p. 575.
(G) Dover Colliery (Gerrard, 1898).
(H) Swindon (Woodward, 1886), p. 299.
(I) Tenbury, Worcester (Richardson, 1930). Anal. 657, p. 180.
(J) Dudley, Worcester (Richardson, 1930), Anal. 669, p. 182.
(K) Astley Deep Mine, Cheshire (De Rance, 1886), p. 66.
(L) Llandrindod Chalybeate Spring (Luke, 1919), p. 144.
(M) Kelso (Suckling, 1943), Anal. 745, p. 402.
(N) Airthrey, Stirling (Glover, 1857), p. 336.
(O) Bridge of Allan, Stirling (Luke, 1919), p. 162.
(P) Pitkeathly, Perthshire (Glover, 1857), p. 331.

of the brines. It is therefore proposed to dismiss any reference to the places or seams in which the waters occur, and draw attention only to their composition. The analyses, recalculated to percentages of ions, are shown in order of decreasing salinity in Table I, columns (6) to (16). The earlier columns, (1) to (5), reproduce the analyses published hitherto. It is at once apparent that the dissolved salts must be almost wholly

chlorides—naturally there can be no sulphates in the presence of barium chloride—and that, in conformity with the fact that the metals are almost wholly sodium and calcium, the chlorine content is approximately constant at 60 per cent. This is equally true of the barium waters of other districts—at Wetherby, Harrogate, Ilkeston, and Llangammarch—and also of the chloride waters, free from barium, which have been found in various parts of Great Britain. The percentage compositions of these brines are given in Table II. It may be mentioned also that similar waters, all emanating from Carboniferous strata, were encountered in several recent borings for oil in this country. All the British chloride waters, with the exception of that at Woodhall Spa in Lincolnshire, are found in pre-Permian rocks ; chiefly in the Coal Measures, but often in the

TABLE III

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
Ba . . .	—	—	—	—	—	1·41	—
Ca . . .	1·20	4·36	·33	·25	·6	7·79	10·65
Mg . . .	3·72	13·74	·08	·03	·2	·92	·95
Na . . .	30·60	11·25	38·86	39·02	38·4	28·35	26·07
CO_3 . . .	·21	—	—	·04	·2	·30	·47
SO_4 . . .	7·69	·28	·47	·44	·1	·01	·73
Cl . . .	55·29	66·17	60·26	60·18	60·5	60·95	60·90
Fe . . .	—	—	—	trace	—	·16	·04
Br . . .	·19	1·78	trace	trace	—	·06	·06
Li . . .	—	—	—	—	—	·01	—
K . . .	1·10	2·42	trace	—	—	·04	·13
Salinity . .	3·500	22·481	15·523	23·374	2·232	6·445	3·290

(i) Average of present ocean (Clarke, 1920), Analysis A, p. 123.
(ii) Average of Dead Sea (Clarke, 1920), Analyses A–M, pp. 164–5.
(iii) Average of Lake Iletsk, Siberia (Clarke, 1920), Analysis B, p. 168.
(iv) Lake Medve, Hungary (Clarke, 1920), Analysis C, p. 168.
(v) Woodhall Spa, Lincolnshire (Glover, 1857), p. 119.
(vi) Average of British chloride waters containing barium.
(vii) Average of British chloride waters without barium.

Lower Carboniferous, and more rarely in Old Red Sandstone and Silurian strata.

The average composition of the modern ocean, together with the average analysis of the British barium and barium-free brines, are given in Table III. Comparing these it follows that if the British brines are "fossil"—the ocean water of a former geological period locked up and buried in the then existing strata—then that ocean must have been of a vastly different composition to the present one ; or else, if of the same percentage composition, it must have been subjected to processes of chemical reaction whilst in the "fossil" state. Neither evaporation, base-exchange, nor dolomitization seem to give the desired changes, even for the barium-free examples. But such processes are highly complicated, as yet not fully understood, and often the subjects of much controversy. Furthermore, it must be remembered that the open ocean of to-day shows remarkably little variation in its degree of salinity ; the average value being 3·5 per cent. In partially land-locked areas, however, this quantity may be as low as

0·7 per cent, as in the upper reaches of the Baltic. But the percentage salinity of the British chloride waters ranges up to 16·1. Such a high degree of salinity would require concentration of the ancient ocean, which is a process involving factors far too complex, and often hypothetical, for the expression of any set rule. Depending upon the depth and site at which samples are taken, some modern inland seas show a wider range in the degree of salinity than that of the ocean, but here again the percentage composition of the salts present in the water remains fairly constant; such variations as are shown in the underground brines certainly do not occur. Indeed, the calcium content of the salts of any present-day inland sea or saline lake is extremely low; it rarely exceeds 1 per cent, but reaches 4 per cent—approximately half the average quantity in the British brines—in the Dead Sea. The latter is the largest of those very rare modern inland waters which are essentially chloride solutions. Its average analysis, quoted in Table III together with those of two chloride lakes, shows that it is exceptionally rich in magnesium and chlorine. The values of the chlorine content of the two lakes, which are practically pure solutions of sodium chloride are similar to the averages of the underground brines (columns (iii), (iv), (vi), and (vii), Table III). One analysis, also included in Table III, of the Woodhall Spa water shows that, at one time, this also was an almost pure solution of sodium chloride.

The remarkably high content of calcium and the occasional presence of barium in the British brines calls for explanation. The analyses show that these brines are now mixtures of sodium and calcium chlorides. It may be that the sodium chloride portion of the brines represent the "fossil" water of some inland lake or lakes similar to the present-day Lakes Iletsk and Medve (the latter is reported to have been recently formed by the sinking of the ground in an area containing rock-salt deposits). On the other hand the sodium chloride solution may have been produced by leaching of rock-salt present in strata as beds or incrustations, the formation of which is favoured by hot desert conditions. Such climates mark the Old and New Red Sandstone periods. If the reddening of the strata immediately beneath the Permo-Carboniferous unconformity, such as occurs in Durham, Cumberland, Yorkshire, and the Forest of Dean, is attributable to desert weathering (Bailey, 1926), then these conditions must have also existed towards the close of the great period of Hercynian denudation. The strata exposed at that time would be Carboniferous and older rocks, and, since the underground brines are found in the sub-strata of the Permo-Carboniferous unconformity, it seems that the origin of these waters may be in some way connected with that period. Whether the brines are "fossil" or whether they are leachings by the passage of younger waters through strata impregnated with rock-salt is debatable, but their wide range in salinity is perhaps more easily explained if the latter origin is admitted.

It remains to find the source of the calcium chloride. This salt does not enter into the proximate formula of the salts in the modern ocean; nevertheless, even if all the calcium were present as the chloride, it would amount to less than one-sixth of the average found in the chloride waters. Taking the Stassfurt deposits as a standard illustration of the products

expected on the evaporation of a salt sea, we find that calcium chloride is present only as a secondary mineral in the form of the hydrated double magnesium-calcium chloride, tachhydrite, the re-solution of which would give a liquor very rich in magnesium. As the British brines have an exceptionally low magnesium content and are at times very rich in calcium, it seems most unlikely that the latter element is residual from sea water. Nor can we look to meteoric waters for the supply of calcium chloride. It is noteworthy that in 1842 the Wallsend Spring on Tyneside, with a salinity thrice that of the ocean, ran 100 per cent calcium chloride with traces of the chlorides of sodium and magnesium, whereas six years later, only 30 per cent of the salt was present, the remainder being sodium chloride with a trace of magnesium chloride (Anal. (1) and (2) in Table I). Analyses of many other British chloride waters show that a change took place in the sodium-calcium ratio from time to time. Thus it seems that a deep-seated origin for the calcium chloride must be sought. It need not necessarily be a primary solution, but may be the result of the passage of liquors, containing reactive chlorine ions, through formations of limestone.

Barium may have been present everywhere in the original calcium solution, and its absence from many of the brines could be explained by its precipitation in contact with sulphate-bearing solutions. On the other hand, the barium may be linked with the Pennine lead-mineralization processes, and its presence in the brines accidental or secondary. It is noteworthy that the known barium waters are not far removed from centres of lead-mining. Galena, either in veinlets or as scattered crystals, is not of uncommon occurrence in the North-East Coalfield, which is itself close to the Weardale galena and barytes deposits ; Wetherby and Harrogate are just to the east of the Grassington lead area, and Ilkeston is on the fringe of the Derbyshire lead district. For all that, at the present, there seems to be insufficient knowledge to decide whether the calcium and barium chlorides in the underground brines are added as one solution, or as two, with separate origins.

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REVIEW

Petroleum Geology of Colombia, South America. By J. L. Anderson. *Bull. Amer. Assoc. Petroleum Geol.*, vol. xxix, pp. 1065–1142. 1945.

The Republic of Colombia ranks eighth among the oil-producing countries of the world, with an annual output of 25 million barrels, and the reserves appear to be very large. The country, with an area of 460,000 square miles, can be divided into two nearly equal and strongly contrasted halves. The eastern half consists of low-lying plains (Llanos), while the western region comprises mainly the usual three cordilleras, Oriental, Central, and Occidental, some peaks rising to 19,000 feet. The general strike of the ranges is N.N.E.–S.S.W., and the two eastern ones occupy the site of the North Andean geosyncline, which was filled with Cretaceous and Tertiary sediments. A little further west lies the slightly younger Bolivar geosyncline. The principal oil-producing region at present is in the valley of the Magdalena River between the eastern and central ranges. Petroleum occurs on asymmetric anticlines which are in places complexly faulted with frequent overthrusting from the east : all these structures are due to the late Tertiary Andean Revolution. Much active exploration is now going on in the north coast region and in the Llanos near the well-known and highly important Venezuelan oilfields.

This publication, which is based on one of the Distinguished Lecture series of the Association, contains a detailed description of the geology of the oil-bearing regions and concludes with a very long bibliography.

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The Hinge of certain Non-Marine Lamellibranchs from the Lenisulcata Zone of the Coal Measures

By R. M. C. Eagar

(PLATES I AND II)

Introduction: Variation and Natural Groups within the Carbonicolidae

PREVIOUS investigation has shown that the non-marine lamellibranchs of the Lenisulcata Zone are liable to vary to an exceptional degree (Wray and Trueman, 1931 and 1934; Wright, 1934 and 1937; Trueman in Hudson and Dunnington, 1939). W. B. Wright considered that forms of higher horizons, especially those of the Modiolaris Zone, might be simulated with sufficient accuracy to deceive, unless a considerable number of specimens were available for study (Wright, 1934*b*, p. 35). Although it is hoped that recent work by the writer on variation in thin shell bands, shortly to be published, will render small collections from the Lenisulcata Zone more readily distinguishable from those of higher horizons, it is still most important to investigate any structural feature, such as the hinge, which may distinguish this group of shells as a whole.

Professor Trueman (1933) recognized two compact and fairly natural groups within the genus *Carbonicola*, that of *C. aquilina* (J. de C. Sowerby) ranging from near the base of the Modiolaris Zone to more than half-way up the Similis-Pulchra Zone, and that of *C. communis* Davies and Trueman characterizing principally the Ovalis Zone. He placed the Carbonicolas from the Lenisulcata Zone provisionally in his *C. recta* group, pointing out that although they might be closely related to the *C. communis* group of the succeeding zone, little was known of their internal characters. It appeared then that their hinge was different in certain respects from that of *C. communis* (Ware and Trueman, 1932, p. 72). The Anthracomyas of the Lenisulcata Zone were placed in a separate group. Wright (1934*a*), with more abundant material than was obtained from the bore-holes in Yorkshire previously investigated, showed that *Carbonicola fallax* W. B. Wright, the most common species in the Lenisulcata Zone of the Lancashire Lower Coal Measures, graded perfectly with certain forms which on their outline are referable to the

genus *Anthracomya* [1]; further that *C. fallax* had a distinct resemblance to *C. aquilina* (J. de C. Sowerby) and *C. concinna* W. B. Wright from the Modiolaris Zone. Indeed Wright regarded his species *C. limax* as being "merely a humpbacked variant of *C. aquilina*" (Wright, 1934*a*, p. 17), and he wrote finally: "*Carbonicola aquilina*, which is dominant in the Modiolaris Zone, is only a rare variant in the Lower Coal Measures" (Wright, 1934*b*, p. 35). Whether Wright merely implied that the simulation of *C. aquilina* [2] was sufficiently close for the adoption of the name on morphological grounds, or whether he implied genetic relationship is not clear.

Dr. R. M. MacLennan (1944) has given a detailed account of the hinge of *Carbonicola pseudorobusta* Trueman and certain related species of the *C. communis* group, demonstrating a wide range of variation in the dental apparatus of these shells. The hinge of the *Carbonicola aquilina* group has long been known to be a comparatively stable feature (King, 1856; Hind, 1894–6; Trueman, 1933), although there is reason to believe that Hind's description of the hinge is incomplete (p. 14). No previous detailed work has been done on the hinge of *Carbonicola* and *Anthracomya* from the Lenisulcata Zone.

Acknowledgments

The writer is very grateful to Professor Trueman and Dr. J. Weir for helpful suggestions, for providing opportunities for discussion, and for reading the manuscript. Many thanks for the loan of material are due to Dr. D. Leitch, Dr. C. J. Stubblefield, Dr. H. C. Versey, Dr. W. Hopkins, and the authorities of the Hancock Museum. The work was carried out while the writer was in receipt of a grant from the Carnegie Trust which is gratefully acknowledged.

The Scope of the Work and its Presentation

Over 290 specimens from the Lenisulcata Zone of the Yorkshire and Lancashire Lower Coal Measures, nearly all originally in the writer's collection, show or suggest some features of the hinge. Of these 190 mostly take the form of impressions or negatives of hinge features preserved in ironstone from which the shelly material has crumbled away or has been dissolved. Stronger shelly material has been obtained from one horizon above the Bassy Mine at Windle, near St. Helens, where ninety-eight hinge plates, among which are eighteen pairs of opposing valves, have been extricated from soft shaly mudstone and cleaned. A list of horizons and localities is placed at the end of this paper.

It is proposed first to describe the more general features of the hinge of shells from the Lenisulcata Zone; secondly to proceed to a more detailed description of the hinge and its variation in a community; thirdly to review briefly what is known of the hinge at different horizons, and finally to discuss the affinities of these shells as a whole.

[1] Davies and Trueman (1927, p. 220) wrote: "So far as general form and certain other characters are concerned, there appears to be at certain horizons a transition from *Carbonicola* to Anthracomya-like shells and from *Anthracomya* to Naiadites-like shells."

[2] His use of this species' name was somewhat loose: *vide Summ. Prog. Geol. Surv. for 1936*, part ii, p. 12, "fig. 5."

1. The Hinge of the *Carbonicola fallax* Group (*sensu lato*)

Under this designation are included *Carbonicola fallax*, *C. protea*, *C. limax*, *C. obliqua*, and *C. haberghamensis* W. B. Wright, and *C. recta* Trueman. What little is known of the hinge of the Anthracomyas of the Lenisulcata Zone, with the added evidence of their perfect gradation to smaller forms of *Carbonicola*, suggests that *Anthracomya lenisulcata* Trueman and *A. bellula* (Bolton) are at least closely related to the *C. fallax* group.

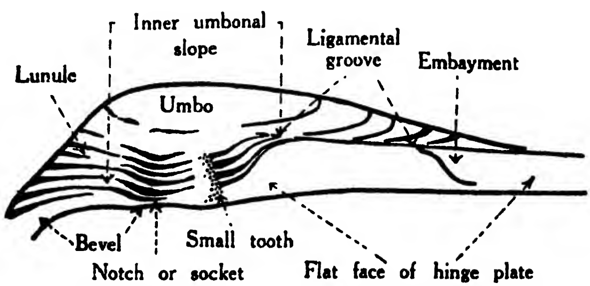
Throughout the group the hinge is a highly variable feature. The variation appears to be continuous and bears little relation to the greatly varying outlines of the shells. While certain forms appear edentulous, in others the hinge plate may be slightly furrowed or undulated, having indefinite swellings corresponding to depressions in the opposing valves, while in yet others, and much less commonly, definite although small teeth may be developed.

The shell is always relatively thick over the umbo, and in small specimens it may be exceptionally thick, contributing as much as 7 per cent of the height of the internal mould of the valve. Well posterior to the umbo a strong hinge plate is developed, having a flat smooth face of contact (Text-fig. 1). Slightly posterior to the umbo, usually about one-third of the length of the shell from the anterior end, the face of contact or inner margin of the hinge plate rapidly becomes narrow as it passes into the marginal bevel of the lunule. Beneath the hinge plate in certain large shells (e.g. in *Carbonicola obliqua* or *C. haberghamensis*) there may be an appreciable subumbonal hollow such as is found in the *C. communis* group. In the smaller more elongate shells there is little or no hollow. Growth lines on the external surface of the shell pass into the lunule, where they are usually somewhat coarse, and are continuous across the anterior portion of the hinge plate and across any undulations, sockets, and usually across any teeth which may be situated upon it. Beneath the umbo, notably when it is small and ill-defined as in small elongate shells, there is an area or inner umbonal slope between the umbo and the hinge margin, merging indefinitely with the lunule, of which it may be considered a backward extension (Text-fig. 1).

Posterior to the umbo in the *C. fallax* group there passes back a narrow groove which presumably received the ends of the external ligament. The groove runs parallel or subparallel to the hinge margin, on or near the edge of the hinge plate, usually directed downward and slightly outward from the vertical median plane of the shell. It is usually seen to be terminated by a small notch or embayment in the hinge plate about two-fifths of the shell length from the posterior end. It may, however, fade out at this point or further to the posterior, or pass off the hinge plate inwards without any terminal embayment. It is best seen in ironstone impressions of the hinge plate (or negatives) where it forms a knife-edge ridge (Pl. II, fig. 8A). When the shell is preserved the groove is usually obscured by matrix, but it can be excavated with care. In some cases it is scarcely more definite than a growth furrow, and occasionally two grooves may be present. In other cases it forms a definite clean-cut feature, separated by a narrow parapet from the flat inner face of the

hinge plate, as MacLennan (1944) has noted in the case of *Carbonicola pseudorobusta* Trueman. In Pl. II, fig. 10, is drawn the dorsal view of a well-preserved shell which has been slightly tilted to show the flat inner face of the hinge plate. The groove in this case is unusually wide and strong and is separated from a slight nymph on the dorsal margin by a second groove.[1] No structure similar to this has been seen in other shells.

Either valve, beneath or anterior to the umbo, may bear one or two swellings or small teeth which are situated generally high on the hinge plate or on the inner umbonal slope, more or less in contact with the umbo (Text-fig. 1). A tooth, swelling, or outward deviation of the hinge margin is apparently always opposed by a socket or depression, which may be similarly situated on the opposite hinge plate, so that tooth and socket may not be in contact with each other when the valves are closed.



TEXT-FIG. 1.—Semi-diagrammatic sketch of the hinge features of a small shell belonging to the *Carbonicola fallax* group. Teeth, when they are developed, and sockets are represented in text-figs. 3 and 4 with the conventions used above.

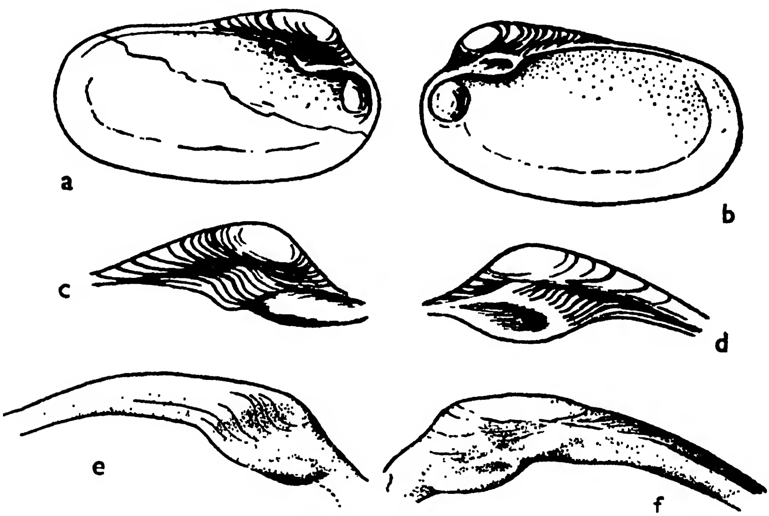
A single swelling on either valve, with opposing notch or depression on the other, is the most common arrangement in the small more elongate shells. Notches or sockets, depressions or deviations in the hinge plate, although they may be so weakly defined as to merge indefinitely with the lunule, are in general stronger features than projections or teeth and they usually extend lower on the hinge plate than do the teeth. A notch or depression in the hinge plate of one valve may not be opposed by an appreciable swelling in the other. These hinge characters indicate that teeth and sockets (using the terms in a broad sense to cover the more indefinite features of the hinge plate) frequently did not engage one another until the valves opened.

Moreover it appears that when the valves were closed, and in certain cases when they were partly opened, a gap was sometimes left between the hinge margins, beneath or anterior to the umbo. Such a gap would probably be filled during life by membranous laminae of periostracum (internal papery ligament) such as is often seen beneath the umbo and in the grooved lunular region of modern freshwater shells, acting as a

[1] It is possible that the second groove may owe its origin to a freak of preservation, or even to erosion.

kind of cushioning mechanism or possibly merely as a barrier to the entrance of foreign material into the dorsal area, as MacLennan (1944) has suggested in the case of *Carbonicola pseudorobusta.*

King (1856), describing *Anthracosia beaniana* (probably *Carbonicola* cf. *aquilina*), noted a gap between the valves formed by grooved opposing notches, termed by him " umbonal ligamental fulcra ", anterior to the umbo but dorsal and posterior to the teeth. He suggested that the gap was occupied by an internal ligament " an anterior expansion of the corselet ligament, taking the form of imperfectly conjoined laminae which in the Unionidae produce a number of curving linear impressions "



TEXT-FIG. 2.—(*a*)–(*d*) Tracings of King's original figures of *Anthracosia beaniana* (from King, 1856, plate iv, figs. (*a*)–(*d*), p. 258).
(*e*) and (*f*) Two specimens marked 5 and 4 respectively from a collection of eight shells in the Hancock Museum labelled " Anthracosia (showing hinge). Ironstone Shale Coll., Whitley, North[umber]-land ".

on the hinge plate. King's use of the term " umbonal ligamental fulcra " is discussed by MacLennan who pointed out that Salter (1861) and Hind (1894–6) have probably misunderstood him, regarding the cavity as being filled by an anterior extension of the external ligament. Dr. Weir has kindly drawn my attention to some specimens in the Hancock Museum labelled " *Anthracosia* " from Whitley Bay, the type locality of *A. beaniana.* These shells (three left and three right valves) bear a fairly close resemblance to King's figures (Text-fig. 2), the originals of which appear to have been lost, and they conform to his description (King, 1856, p. 51) in which he mentions that the notch of the left valve is more deeply excavated than that of the right. The notch, however, appears to have been quite a different feature from that found in *C. fallax.* In the Hancock Museum specimens the low massive teeth are clearly separated from the furrowed notches. As the shell opened, the notches, which are strongly concave

would have been held apart to some extent by the teeth, both of which are seen in dorsal view to project out markedly from the hinge plate. The socket in the three right valves seen is comparatively shallow and separated by a ridge from the notch slightly posterior and dorsal to it. In *Carbonicola fallax* and related shells notches below the umbo or in the hinge plates are closely associated with swellings and less commonly teeth, which are situated high on the hinge plate or on the inner umbonal slope. As the shell opened the notches must have tended to be more or less filled, or partly rolled against each other. Whatever interpretation may be given to King's " umbonal ligamental fulcra ", it appears from his figures and from the Hancock Museum specimens that they are structures essentially different from those found in the *C. fallax* group.

The hinge of the *C. fallax* group is unspecialized and its mechanical efficiency must usually have been low. In eleven out of eighteen pairs of opposing valves from Windle, St. Helens, the fit of one valve against the other is the most close, and the mechanism as a whole the most adaptable for movement if it is assumed that the left valve slightly overlapped the right over a varying length of the hinge margin anterior to the umbo, that is to say over part of the marginal bevel. The margin or bevel of the left valve is here slightly thicker than that of the right (Pl. I, figs. 11 and 14) and may have a smooth convex surface which, as the valves opened, would roll against the sloping concave lower portion of the lunule or inner umbonal slope. Any weak teeth and sockets would tend to come into contact with one another as the opening continued. This arrangement, in which an overlap is believed to have taken place, may be combined with deviations or swellings in the hinge plate (e.g. Pl. I, fig. 14). In four cases no overlap is required for a good fit, preservation in the remaining three cases being too incomplete for any inference to be drawn.

2. Hinge Structure in a Community of Small Shells

Over 130 specimens of *Carbonicola* have been collected from a horizon at Windle, St. Helens (p. 10) 60 feet above the Bassy Mine, smaller quantities of similar material having been obtained down to 2 feet below this horizon and at 3 ft. 6 in. above it. Shells collected from 58–63 feet above the coal are here considered together since throughout this thickness the fauna shows no appreciable change.[1]

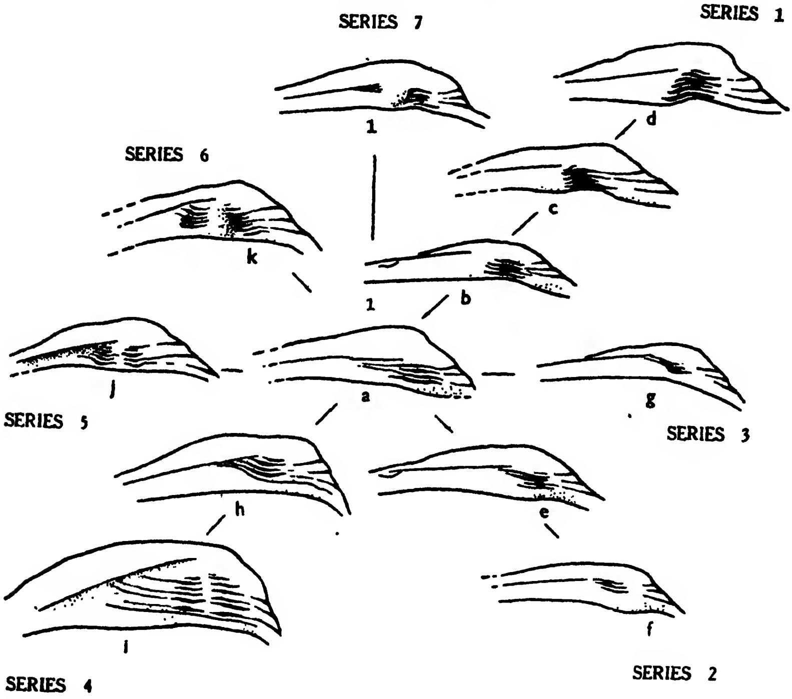
The shells are small and elongate with ill-defined umbones, a short anterior end, straight or slight reflected lower borders and oblique or rectangular truncation. Although the length varies between 10 and 35 mm. the variation is distinctly limited. No shells have a height/length ratio as great as that of the holotype of *Carbonicola fallax* (46·5 per cent) nor length of anterior end/length ratio [2] as great as 25 per cent. The forms are referable to *Carbonicola* aff. *fallax* W. B. Wright (elongate: compare Wright, 1934*b*, p. 28, fig. 4A), *C.* cf. *recta* Trueman (elongate,

[1] The writer has a detailed section of the succession which it is hoped to publish at a later date.

[2] Measurements for the ratios height/length (H/L) and length of anterior end/length (A/L) have been taken in the manner defined by Davies and Trueman, 1927.

with short anterior end), *C.* aff. *limax* W. B. Wright (Wright, 1934*b*, p. 28, fig. 4F), and more uncommonly *C. limax*. Two shells grading with *C.* aff. *limax* appear referable on their outline to *Anthracomya* sp.

Preservation is good, but the shelly material is very fragile. When both valves of the animal are present together they are usually crushed on each other, especially in the region of the ventral border where the shell is thin. Many of the best specimens of hinge features consist of little more



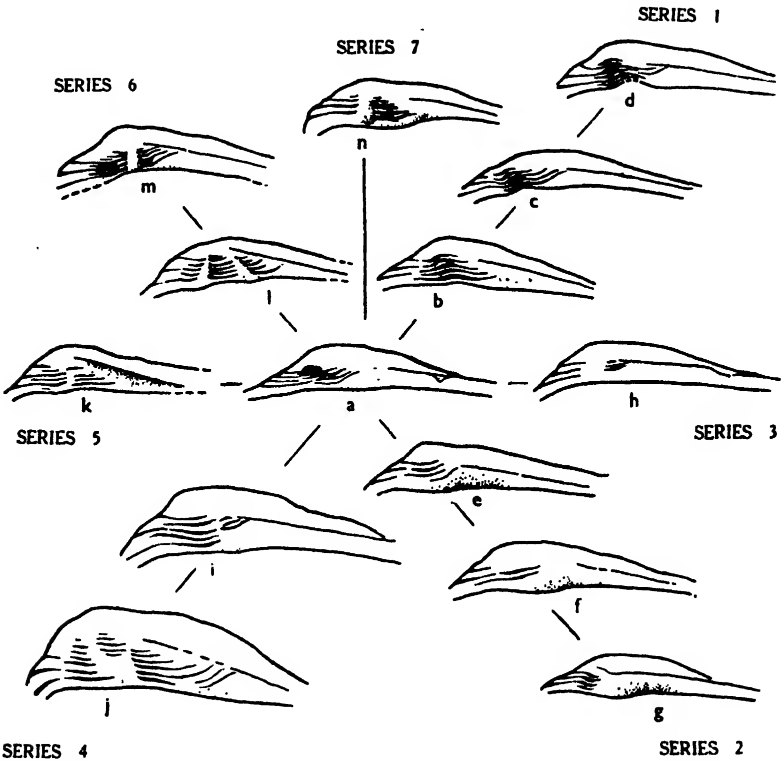
TEXT-FIG. 3.—Hinge plates of the left valve in a community of small shells of the *C. fallax* group arranged in a variation diagram. The registered numbers of the specimens in the Hunterian Museum are in order (*a*)–(*l*): S. 13145, 13152, 13146*a*, 13149, 13144, 13148, 13160, 13143, 13142*a*, 13150*a*, 13151, 13147*a*.

than the hinge plates, the thin part of the shell towards the margins having been broken or having crumbled away.

The features of the hinge are very variable (Pl. I). Some shells appear quite edentulous, but in nearly every case there is some slight deviation in the hinge margin which often may be best seen when the shell is viewed dorsally (fig. 5). Deviations, swellings, or depressions on the hinge plate are much more common than are small teeth.

Text-figs. 3 and 4 show diagrams of the variation of the hinge plates of the left and right valves respectively. The arrangement is made for convenience of description only and it is not suggested that the series have necessarily evolved from the central norms. The dorsal views of

the hinge margins of the first three series are shown in Text-fig. 5. In the norms (*a*) for both valves (see also Text-figs. 5*a* and *a'*) a notch is developed on the hinge plate and inner umbonal slope, anterior or posterior to which there is a slight swelling. In Series 1 the notch becomes deeper and tends to be situated lower on the hinge plate while the slight swellings finally disappear. In Series 2 the notch becomes more shallow, being ultimately situated on the inner umbonal slope where it may disappear, whereas the swellings become more pronounced and definite. It will

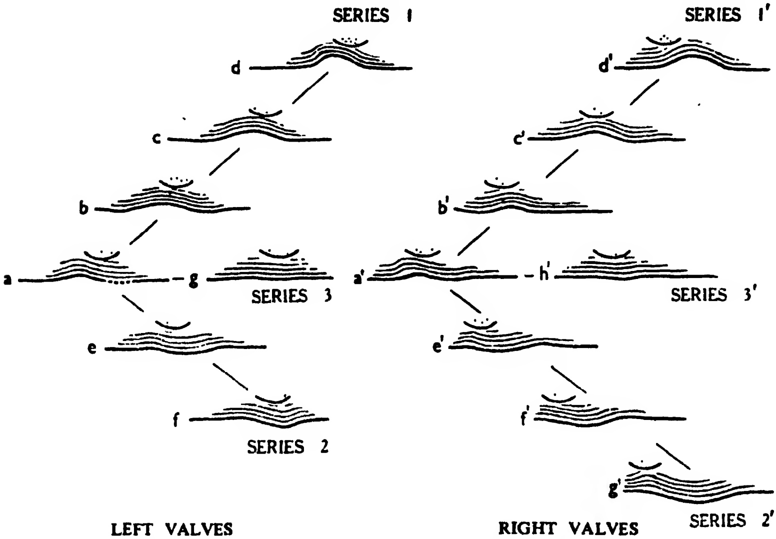


TEXT-FIG. 4.—Hinge plates of the right valve in a community of small shells of the *C. fallax* group arranged in a variation diagram. The registered numbers of the specimens in the Hunterian Museum are in order (*a*)–(*n*) : S. 13156, 13154, 13162, 13163, 13159, 13146*b*, 13158, 13153, 13155, 13142*b*, 13157, 13150*b*, 13161, 13147*b*.

be noted that the swelling tends to be placed anterior to the notch on the left valve and posterior to the notch on the right valve, although this arrangement is not invariable. A number of almost perfect cases of dental transposition are figured (e.g. Text-figs. 3*d* and 4*d*, 3*g* and 4*h* ; compare also Pl. I, figs. 1 and 2, etc.). Notches or depressions tend to be more definite features than the swellings, and they are more common on the left valve than on the right. In Series 3 (Text-figs. 3 and 4) the notch becomes very small, being placed high at the posterior end of the

inner umbonal slope, the hinge margin, seen dorsally, becoming practically straight (Text-figs. 5*g* and *h'*). By far the greater proportion of the shells examined fall on or between Series 1, 2, or 3.

Of the remainder, Series 4 is represented by slightly larger shells than the others, having the umbones raised to give a slightly concave, sharply inclined inner umbonal slope, the surface of which may be undulated. The slope is bounded in the left valve by a projecting margin, thickened



TEXT-FIG. 5.—Diagrammatic representation of the dorsal view of the hinge margin with hinge plate and inner umbonal slope (conventional lines) and umbo (dotted) of the shells drawn as Series 1–3 in text-figs. 3 and 4.

and somewhat rounded and seen in dorsal view to be deviated, in the case of the specimen drawn in Text-fig. 3*i*, from the anterior first outward toward the right valve and then inward toward the umbo. The margin of the right valve is comparatively sharp, and in Text-fig. 4*j* (the pair of Text-fig. 3*i*) shows a single inward deviation. The fit of this valve pair has already been referred to and discussed.

In most of the shells of the community a narrow parapet separates the ligament groove from the inner face of the hinge plate. In Series 5 the parapet is accentuated to form a strong sharp ridge (Pl. I, figs. 7 and 11). Although this structure may be more fully developed on one valve than on the other, it is clear from its presence in valve pairs, that the ridge cannot have functioned in any way as a lateral tooth. It would appear rather to have provided a barrier to the opening of the valves beyond a certain limit.

In Series 6 and 7, in both right and left valves, small teeth may be developed, principally on the inner umbonal slope, being opposed by shallow sockets (compare Text-figs. 3*l* and 4*l* and Pl. I, figs. 10 and 11). The teeth are weak features, scarcely projecting from the hinge plate and

inner umbonal slope, and they apparently rolled into contact with the lower part of the sockets as the valves opened. In the few valves where definite teeth are present their arrangement is slightly different, and it is probable that further collecting would show continuous and somewhat indefinite variation in the dental pattern. The teeth, however, never reach the strength and definition which is commonly seen in *Carbonicola pseudorobusta* Trueman and the writer has seen no specimen in which there is any approach to the more complicated patterns figured by MacLennan (e.g. 1944, plate, figs. 5, 12, and 14).

There does not appear to be any relationship between the shape of the shell and the character of the hinge. Series 4, however, is probably restricted to the larger shells.

3. Notes on the Hinge Features of Shells from Different Horizons

A preliminary examination has been made of a *Carbonicola* fauna from a horizon at Upholland, near Wigan, believed by the writer to lie a few feet below the base of the Lower Coal Measures.[1] It can only be stated that the pattern of the hinge is quite different from that of *C. aquilina* and appears very comparable with that of the community described above.

About ninety ironstone moulds from 0–5 feet above the Bassy Mine at Windle Cutting, St. Helens, show or suggest features of the hinge plate or inner umbonal slope. The variation is comparatively limited and distinctly different from that found in the fauna 60 feet above the coal described above. The shells are referable to *C. fallax* W. B. Wright (Text-fig. 7*a*), *C.* aff. *fallax* (mostly with straight ventral borders, including forms both longer and shorter than the holotype), *C.* aff. *recta* Trueman, *C.* cf. *sulcata* Wright, 1934*b* (non Brown), with occasional elliptical forms (Text-fig. 7*c*) and Anthracomya-like variants.

Teeth are much less commonly developed than are swellings on the hinge plate. Internal and external moulds of the same specimen, with valves more or less in the position of closure, indicate that although teeth or swellings may be present they do not usually extend sufficiently low on the hinge plate to cause an appreciable deviation in the median ridge of the internal mould. If the ridge is high, however, there may be a gentle deviation, which is more often towards the left valve than towards the right (Pl. II, fig. 4). Two fine specimens in the collection of the Geological Survey have rather more of the median ridge preserved than is usual and show definite teeth (Pl. II, figs. 2 and 3). The arrangement in fig. 3 presumably indicates a transposition of that seen in fig. 2 and appears at first sight very comparable with that commonly seen in *Carbonicola aquilina*. It should be apparent, however, from the drawings that the teeth are set considerably higher on the hinge plate in these specimens than in *C. aquilina*.[2]

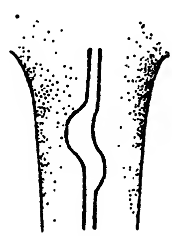
Sockets or notches usually extend lower on the hinge plate than do

[1] See Jones, Tonks, and Wright, 1938, pp. 11–16; this horizon will be discussed in a later paper.

[2] The differences between casts of *C. fallax* and *C. aquilina* are fully discussed in a later section (p. 15).

the teeth, and they vary greatly in definition. Usually the notch is set higher on the hinge plate and inner umbonal slope on the left valve than on the right. It is usually more strongly developed in the left valve and its axis pitches more, that is to say, forms a larger angle (measured dorsally) with the vertical median plane of the shell in the left valve than in the right. Where no definite teeth are developed it is found that the notches are not placed directly opposite one another, although when large and indefinite they must overlap to some extent. In the most frequently occurring pattern seen at this horizon the notch of the left valve is placed slightly anterior to that of the right which is weaker and situated lower on the hinge plate. A slight swelling may then be developed on the right valve opposite to but not filling the notch on the left. This arrangement is well seen in the specimen S. 13141, shown diagrammatically in Text-fig. 6.

Ironstone moulds on a comparable horizon, a few feet above the Soft Bed Coal at Stocksbridge, near Sheffield, show a very similar suite of



TEXT-FIG. 6.—Diagrammatic representation of the margins of opposing hinge plates of *Carbonicola*, viewed dorsally with the anterior of the shell to the north, showing a common arrangement found in *C. fallax* collected 0–5 feet above the Bassy Mine, Windle, St. Helens. The positions of the umbones are indicated by the shading. From specimen S. 13141, in the Hunterian Museum.

variants to those described above from Windle, 0–5 feet above the Bassy Mine. In the thirteen available specimens, however, teeth or swellings appear as common on the left valve as on the right.

Ironstone moulds of the hinge plate from slightly higher horizons above the Soft Bed in Yorkshire show the usual wide variation in the shape and definition of notches or sockets in the hinge plates of the smaller shells. Compare the specimen shown in Pl. II, fig. 7B, where the striations of the notch close at either end, with that of fig. 11 in which there is but a gentle depression on the inner umbonal slope. The median ridge of the internal mould is rarely deviated. In the specimen shown in Pl. II, fig. 1, the ridge is exceptionally high and sharp, and only the upper portion shows the deviation.

The hinge of the larger shells, *Carbonicola protea* and *C. haberghamensis*, appears similar to that of the small shells, but less is known of its variation at present. Fourteen specimens, mostly referable to *C. haberghamensis*, collected 19 ft. 9 in. to 20 ft. above the Soft Bed Coal at Honley, near Huddersfield, show moulds in ironstone of the hinge plate, but in no case are there moulds of opposing valves. In every case in the nine specimens from the right valve the notch is low and its axis makes a

small angle with the vertical median plane of the shell, measured dorsally. In all but one case the notch is a well defined feature in which the striations appear to close at either end. Its shape, however, is variable (compare Pl. II, figs. 6, 9B, and 12). The type of striation is, also variable, being coarse in fig. 6 and rather fine in fig. 9B. One large valve (Hunterian Museum, S. 12788D) shows no definite notch, but merely a coarsely-striated area bevelling the inner umbonal slope. In the left valve the notch is high on the hinge plate in two cases, its axis pitching at an angle of about 45 degrees, and two other specimens suggest a fairly high notch. A tooth, also set high on the hinge plate, is seen in one right valve (S. 13017). Five incomplete moulds of hinge features from the type locality of *C. haberghamensis* W. B. Wright, near Burnley, show or suggest a high notch in the left valve and a low notch in the right. In both localities the greater height and more nearly horizontal pitch of the notch in the left valve contrasts with its lower position and more nearly vertical pitch in the right valve. This tendency in the arrangement of the notches has already been noted in a collection of small shells from a slightly lower horizon.

Fifteen ironstone moulds of parts of hinge features have been collected from 24 to 25 feet above the Soft Bed Coal at Honley, a horizon near that of the community at Windle 60 feet above the Bassy Mine. Although swellings are clearly present no certain evidence of teeth has been found. Notches on the hinge plate, however, similar to those already described, may be developed on shells referable on their outline to *Anthracomya* (Pl. II, figs. 8A and B, in which is also seen the ligamental groove and its terminal notch). With regard to the *Anthracomyas* as a group in the Lenisulcata Zone of the Coal Measures the writer has insufficient material showing internal features to write a general account of their hinge. Since, however, the few specimens which have been examined indicate subumbonal notches and ligamental grooves similar to those seen in *Carbonicola*, and since *Anthracomya* shows perfect gradation in outline with *Carbonicola* in communities, where it may contribute any proportion of the fauna from 0–90 per cent, it seems reasonable to suppose, at least provisionally, that the hinge of the Anthracomyas is of the same type as that of the small *Carbonicolas* and probably varies in a similar manner. Problems of the nomenclature of these shells must remain for discussion in a later paper.

The hinges seen in four specimens of *Carbonicola* from below the Middle Mountain Mine of Ravenhead Brickworks, Upholland, appear very comparable with patterns seen in the *C. communis-C. pseudorobusta* group.

4. The Affinities of the *Carbonicola fallax* Group

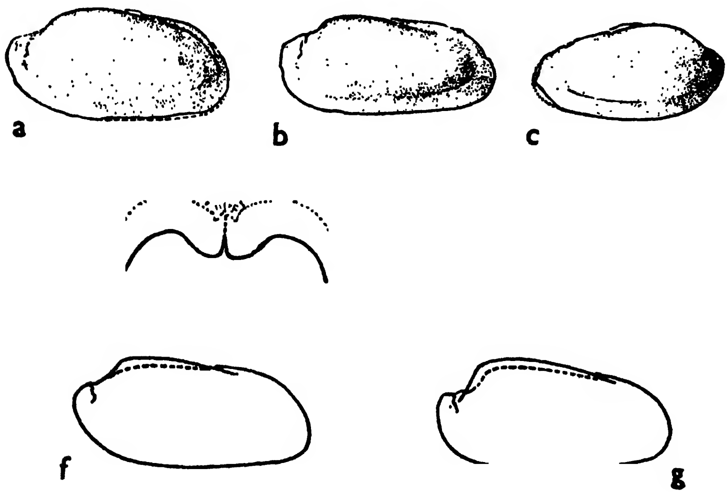
Although the hinge of the *C. fallax* group is different in many of its varieties from any hinge type previously described in the Carbonicolidae, the basal features of the hinge appear essentially similar to those found in the hinge of the *C. communis–C. pseudorobusta* group.

(1) In both groups a thick strong hinge plate is developed, having a flat inner face of contact posterior to the umbo, at least as far to the posterior as the terminal ligamental notch or embayment. The base of

the hinge plate is more or less straight or gently curved from anterior to posterior. The latter feature is reflected in the dorsal surface of internal moulds of shells, which is without angulation between the portion anterior to and that posterior to the umbo (Text-fig. 7*f*).

(2) Teeth, when developed, or sockets, are set high on the hinge plate extending frequently to the inner umbonal slope where they may be in contact with the umbo.

(3) The dentition is extremely variable both in definition of feature and in pattern.



TEXT-FIG. 7.—(*a*) *Carbonicola fallax* W. B. Wright, Geol. Surv. Coll. No. 53023 ; (*b*) *C.* aff. *fallax*. No. 53022 ; (*c*) *C.* cf. *fallax* No. 53042. From 0–5 feet above the Bassy Mine, Windle, St. Helens. Figured Wright 1934*b*, figs. 3L, 3K, and 6B respectively. The specimens are shown in dorsal view in Plate II, figs. 2, 3*a*, and 4 respectively.

(*d*) and (*e*): Diagrammatic enlarged sections of the dorsal post-umbonal portion of a typical internal mould of (*d*) *C. fallax* and (*e*) *C. aquilina* showing the difference in the shape of the median ridge. The dotted lines show the hypothetical thickness and configuration of the overlying shell and ligament.

(*f*) and (*g*): Typical forms of *C. fallax* (*f*) and *C. aquilina* (*g*). The broken line shows the surface of the mid-dorsal portion, between the median ridge and the umbonal shoulders.

In the *C. fallax* group several of the larger forms, having umbones elevated well above the hinge line, appear very similar in their hinge to characteristic types of the *C. communis–C. pseudorobusta* group. Smaller shells, however, with low umbones show a certain degree of similarity in both their external and internal features to members of the *C. aquilina* group, with which they have in the past been compared. From the latter group they may be distinguished without much difficulty if solid material is available.

The Distinction between C. fallax and the C. aquilina Groups

In the following tabulated comparison of the two groups reference will be made to certain parts of the hinge of *C. aquilina* which now appear to be adequately described in Hind's account of the species (Hind, 1894–6).

(1) In *C. aquilina* (s.l.) the hinge plate posterior to the umbones is shallow and is set at an angle with the anterior and deeper part of the hinge plate which projects strongly downward to bear a low massive tooth (Text-fig. 2). Hind pointed out that there was no plate of shell connecting the portions. In internal moulds, owing to the shape of the hinge plate, the post-umbonal mid-dorsal portion, which is sunk between the umbonal shoulders and divided into two grooves by a strong median ridge showing the line of junction of the hinge plates, is set at an angle with the median anterior more excavated portion of the mould (Text-fig. 7*g*).

In *C. fallax* and related shells the hinge plate posterior to the umbo is comparatively deep, having a flat face of contact and a base straight or continuously curved from posterior to anterior as it passes forward into the marginal bevel of the lunular region and the inner umbonal slope. In internal moulds the anterior and posterior parts of the sunken median area between the umbonal shoulders are in line with each other or there is a continuous slight curvature from anterior to posterior (Text-fig. 7*f*).

(2) According to Hind (1894–6, p. 70) the teeth in *Carbonicola aquilina* are low and massive and have apparently a constant pattern, one tooth being found on each valve " of which that in the left is slightly anterior to that in the right ".

In *C. fallax* and associated shells the teeth are set high on the hinge plate, being usually indefinite in development and extremely variable in pattern.

Hind (1894–6, p. 70), describing the teeth of *C. aquilina*, quotes from King's original description of *Anthracosia beaniana* (King, 1856, p. 51) : " crown of tooth of right valve excavated anteriorly (and below) and ridged posteriorly ; crown of tooth of left valve ridged anteriorly and sloped posteriorly." Hind points out that the dorsal median ridge of the internal mould, marking the line of junction of the basal parts of the hinge plates is " deviated from before backwards, first to the right and then to the left, demonstrating the presence of cardinal teeth in the valves, of which that in the left is slightly anterior to that in the right " (Hind, 1894–6, plate x, figs. 19*a* and 21*a*, the specimen in the latter figure showing especially well the deviations in the median ridge which he describes). Hind noted finally that " the hinge characters appear to be constant, and to bear out Professor King's observations ", and that he had met with no variations except that of degree in the form of the hinge. He figures, however, in dorsal view, another internal mould of *C. aquilina* in which there is a fairly strong deviation of the ridge towards the left valve, but no appreciably deviation towards the right. Now the writer has recently examined several collections of *C. aquilina* (s.l.) from the Modiolaris Zone of Derbyshire and Yorkshire (for localities see p. 17) and from the Similis-Pulchra Zone of Scotland, also collections of good

internal moulds from various other horizons now in the Geology Department of Glasgow University. In all these collections 95–100 per cent of the specimens (in the case of the Derbyshire material 60 moulds) showed a deviation of the median ridge of variable strength towards the left valve, but no definite deviation towards the right (compare Hind, 1894–6, plate x, fig. 20*a*, or Clift and Trueman, 1929, fig. 8*bi*). It does not appear clear to the writer how the presence of a single inward deviation of the ridge towards the left valve may be reconciled with a dental pattern such as King and Hind have described. Moreover in one specimen (Geological Survey collection number Sy 563) from above the Ell Coal, Shirland, Derby, the median ridge is deviated from the anterior first toward the left valve and then strongly towards the right, thus suggesting a transposition of the dentition King first described.

Although the hinge of *Carbonicola aquilina* (s.l.) may not prove with further work to be quite as stable a feature as has hitherto been supposed, it is still clearly distinct from that of *C. fallax* group. In the latter the median ridge is usually straight, very slightly deviated, if much of the ridge is preserved (Pl. II, figs. 1 and 4), or thick due to the presence of notches which are not filled by opposing swellings or teeth. When a slight deviation is developed, however, it is more commonly towards the left valve than towards the right.

(3) Internal moulds of *C. aquilina* (s.l.) show in dorsal view two well defined grooves posterior to the umbo, formed between the median ridge, which is thick at its base, and the post-umbonal shoulders, extending usually for at least three-quarters of the length of the shell. Although the grooves become more shallow towards the posterior end there is in most cases a " closure " between them and the median ridge at their termination (see Hind, 1894–6, plate x, figs. 19*a* and 21*a*).

In moulds of *C. fallax* somewhat similar grooves are present in the umbonal and immediate post-umbonal region, but they rapidly loose definition midway along the length of the shell and become lost (contrast Pl. II, figs. 1–4, with Hind, 1894–6, plate x, figs. 19*a* and 21*a*). In members of the *fallax* group the umbones are not infrequently slightly evert, with grooves consequently shorter than are shown on Pl. II. Although the difference in the grooves may appear insignificant in descriptive terms it is easily recognizable in the specimens.

It is also worth noting that sharpness of the grooves in *C. aquilina* is accentuated by the thickness of the base of the median ridge posterior to the umbo ; whereas in *C. fallax* the ridge tends to be more thin along this part of the shell, presumably on account of the flat face of contact of the hinge plate (see fig. 7*d* and *e*), and the grooves are consequently less definite features.

(4) in *C. aquilina* (s.l.) the anterior umbonal shoulders are well defined by a fold between them and the prominent anterior muscle scar (Text-fig. 7*g*).

In *C. fallax* the anterior umbonal shoulders are more blunt and are not clearly defined below the level of the top of the anterior muscle scar (Text-figs. 7*a*, *b*, and *f*).

(5) In dorsal profile moulds and shells of *C. aquilina* (s.l.) show parallelism of the sides and tend to have compressed ends, the com-

pression at the anterior end causing the fold of the anterior umbonal shoulders referred to above.

In dorsal view *C. fallax* (Pl. II, figs. 1–4) does not show such definite parallelism of the sides, nor such definite compression at the ends.

(6) Although *C. fallax* and *C. aquilina* both may have notches in the hinge plate or inner umbonal slope, more or less opposed to each other, these notches are of a different nature in the two groups and presumably had a different function (see p. 6 where the point is more fully discussed).

5. Summary and Conclusions

(1) The *Carbonicola fallax* group of shells, which characterize the Lenisulcata Zone of the Coal Measures, is an extremely variable one comprising a wide range of forms, between which there appears to be perfect gradation.

(2) The hinge of the group is also a highly variable feature, bearing little relation to the outline of the shells. Its variation, however, is more fully known in small forms than in large ones.

(3) Evidence submitted in the present paper indicates that, although the hinge pattern of the *C. aquilina* group may not be as constant a feature as has hitherto been supposed, the group is distinct from that of *C. fallax*. There is no evidence suggesting genetic relationship. A basis for the distinction between internal moulds of *C. aquilina* and *C. fallax* is fully described.

(4) The basic features of the hinge of the *C. fallax* group are essentially those which characterize the *Carbonicola pseudorobusta–C. communis* group of the Ovalis Zone. While certain of the hinges of the larger shells appear typical of the latter group there are a number of other patterns which have not previously been described in the Carbonicolidae.

(5) The hinge features of the *C. fallax* group appear less specialized than those of shells from the Ovalis Zone, especially *Carbonicola pseudorobusta* Trueman (MacLennan, 1944).

(*a*) Large strong teeth have not been seen. Definite small teeth are not commonly developed. It is usual to find gentle swellings on the hinge plate corresponding to depressions in the opposing valve. Some forms are quite edentulous.

(*b*) Only one tooth has been found in either valve, although more than one swelling or depression may be present. There is no approach to the more complicated patterns figured by MacLennan (1944).

(*c*) In most cases engagement of the dental apparatus would only take place as the valves opened. Notches or sockets in the hinge plate are not necessarily opposed by teeth or swellings, but they would have been more or less filled as the opening continued, when the hinge plates apparently rolled against one another.

(*d*) In a community of small shells there is evidence to suggest that in several cases the hinge margin of the left valve slightly overlapped that of the right for a short distance anterior to the umbo.

(6) The range of variation of hinge characters in a community is very large. Collections from different horizons, however, may indicate individual peculiarities or tendencies in the variation. Whether these owe their origin to local conditions or evolution is not yet clear.

(7) The hinge of *Anthracomya* from the Lenisulcata Zone is as yet little known. What evidence there is points to a hinge similar to that of small *Carbonicola* showing the same type of variation.

LIST OF LOCALITIES FROM WHICH MATERIAL HAS BEEN EXAMINED

(*a*) From the Lower Coal Measures of Yorkshire and Lancashire.

(i) East bank of cutting at the southern end of a short tunnel 100 yards north of Honley railway station, 2½ miles south-south-west of Huddersfield. One-inch N.S. 86, six-inch Yorks. 260 S.E. Various horizons above the Soft Bed Coal.

(ii) West bank of the Little Don, about 50 yards south of the northern gate to Messrs. Samuel Fox Works, Stocksbridge, near Sheffield. One-inch N.S. 87, six-inch Yorks. 282 S.W. 10–14 feet above the Soft Bed Coal.

(iii) Cutting in the private railway line of the Hepworth Iron Works, 1 mile south-east of Hazlehead Colliery, about 30 yards north of the bridge carrying the Millhouse Green–Longley road, Hazlehead, near Holmfirth. One-inch N.S. 86, six-inch Yorks. 273 S.W. About 50 feet above the Soft Bed Coal.

(iv) Cutting in the Liverpool–Manchester New Road on either side of a footbridge 720 yards E. 10° N. of Windle Smithies, near Denton's Green, St. Helens. One-inch N.S. 84, six-inch Lancs. 100 S.E.E. 6 inches—5 feet and 58–63 feet above the Bassy Mine.

(v) Section in New Barn Clough, 250 yards north-west of Micklehurst Farm, Habergham Eaves, Burnley. One-inch N.S. 76, six-inch Lancs. 64 S.W. About 19 feet above the Bassy Mine.

(vi) Tip heaps of Upholland Colliery and Byeproducts Co., 280 yards E.S.E. of Upholland railway station, near Wigan. One-inch N.S. 76, six-inch Lancs. 64 S.W. Above the Lower Mountain Mine of Upholland.

(vii) Ravenhead Brickworks Quarry, Holland Moor, 1 mile west of Upholland. Map reference as in (vi) above. About 25 feet below the Middle Mountain Mine of Upholland.

(*b*) From the Middle Coal Measures.

(i) Whiteley's Plantation Opencast Site, 800 yards N. 71° W. of Prospect Farm, 1 mile east of Smalley, Derby. One-inch 25, six-inch Derby 45 N.E.E. About 30 feet above the Waterloo Coal.

(ii) Stonebarrow Lane Opencast Site, 1,000 yards N. 25° E. of St. Leonard's Church, Shirland. One-inch 112, six-inch Derby 35 N.E.E. Up to 6 feet above the Ell Coal.

(iii) Tip heaps of Crigglestone Colliery, near Wakefield. One-inch N.S. 78, six-inch Yorks. 248 S.W.

(iv) Sourlie Pit, Irvine, North Ayrshire.

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EXPLANATION OF THE PLATES

PLATE I

A number of hinge plates of small *Carbonicola* of the *C. fallax* group, from a cutting in the Liverpool–Manchester New Road, near Windle, St. Helens, 60 feet above the Bassy Mine. The specimens shown in figs. 1 and 9 are from a horizon 3 ft. 6 in. above that of the remainder. Left and right valves are shown in opposing columns. Figs. 3 and 4, 7 and 13, 10 and 11, and 14 and 17 are opposing valves of the same animals. All are magnified three times and are included in the variation diagrams of text-figs. 3, 4, and 5, where they are represented semi-diagrammatically.

The Hunterian Museum numbers are, in order, figs. 1–17, S. 13160, 13153, 13146*a*, 13146*b*, 13144, 13158, 13150*a*, 13156, 13162, 13147*a*, 13147*b*, 13143, 13150*b*, 13142*a*, 13161, 13151, and 13142*b*.

PLATE II

Hinge features and other internal characters of shells of the *Carbonicola fallax* group. The specimens shown in figs. 1, 5, and 7 have been collected from a cutting in a private railway line to Hazlehead Colliery, Hazlehead, near Holmfirth, about 50 feet above the Soft Bed Coal: those of figs. 2, 3, and 4 from a cutting in the Liverpool–Manchester New Road near Windle, St. Helens, 0–4 feet above the Bassy Mine; those of figs. 6, 8, 9, 11, and 12 from a cutting at Honley Railway Station, near Huddersfield, at different horizons above the Soft Bed Coal detailed below.

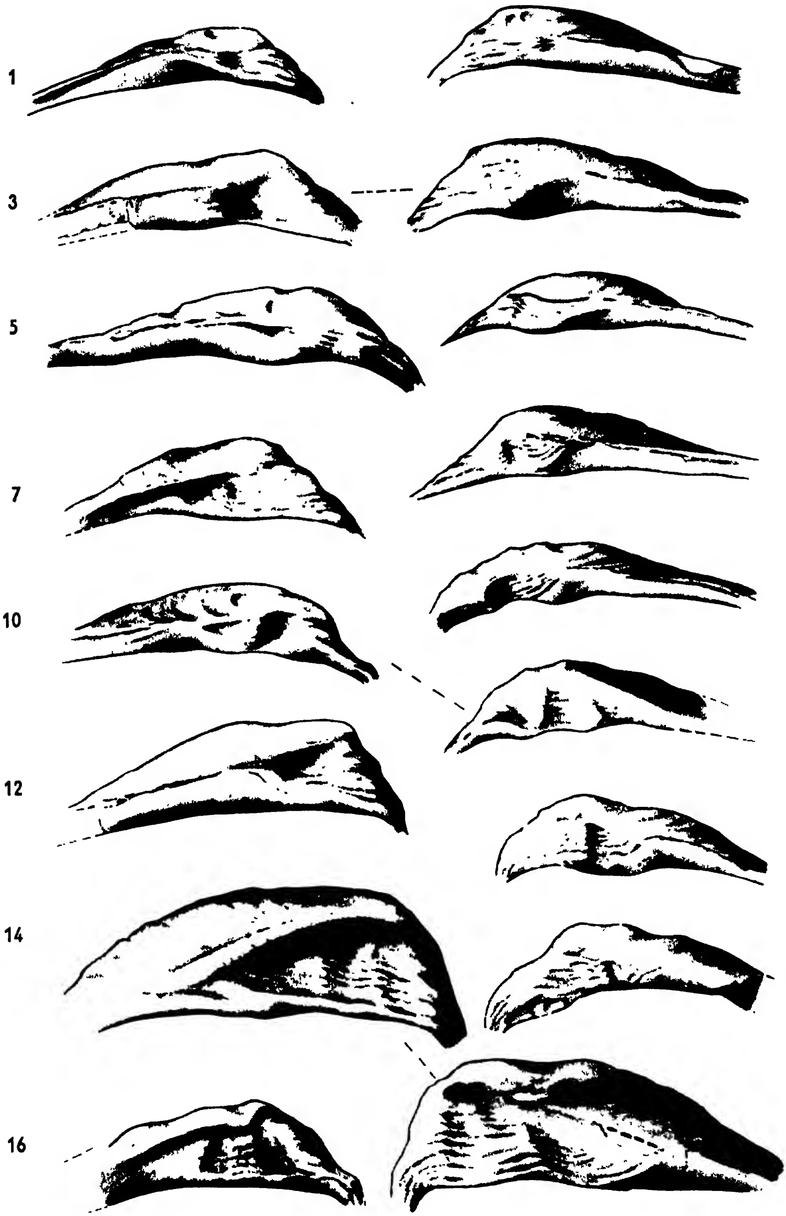
FIG. 1.—Internal mould of *Carbonicola* aff. *fallax* (small): fig. 1A dorsal view, and fig. 1B view from anterior end. From Hazlehead. × 2. Hunterian Museum, No. S. 13086.

FIG. 2.—Internal mould of *Carbonicola fallax*, dorsal view. The lateral view is shown in text-fig. 7A. From Windle. × 1·5. Figured Wright, 1934*b*, p. 27, fig. 3L. Geol. Surv. Coll. No. 53023.

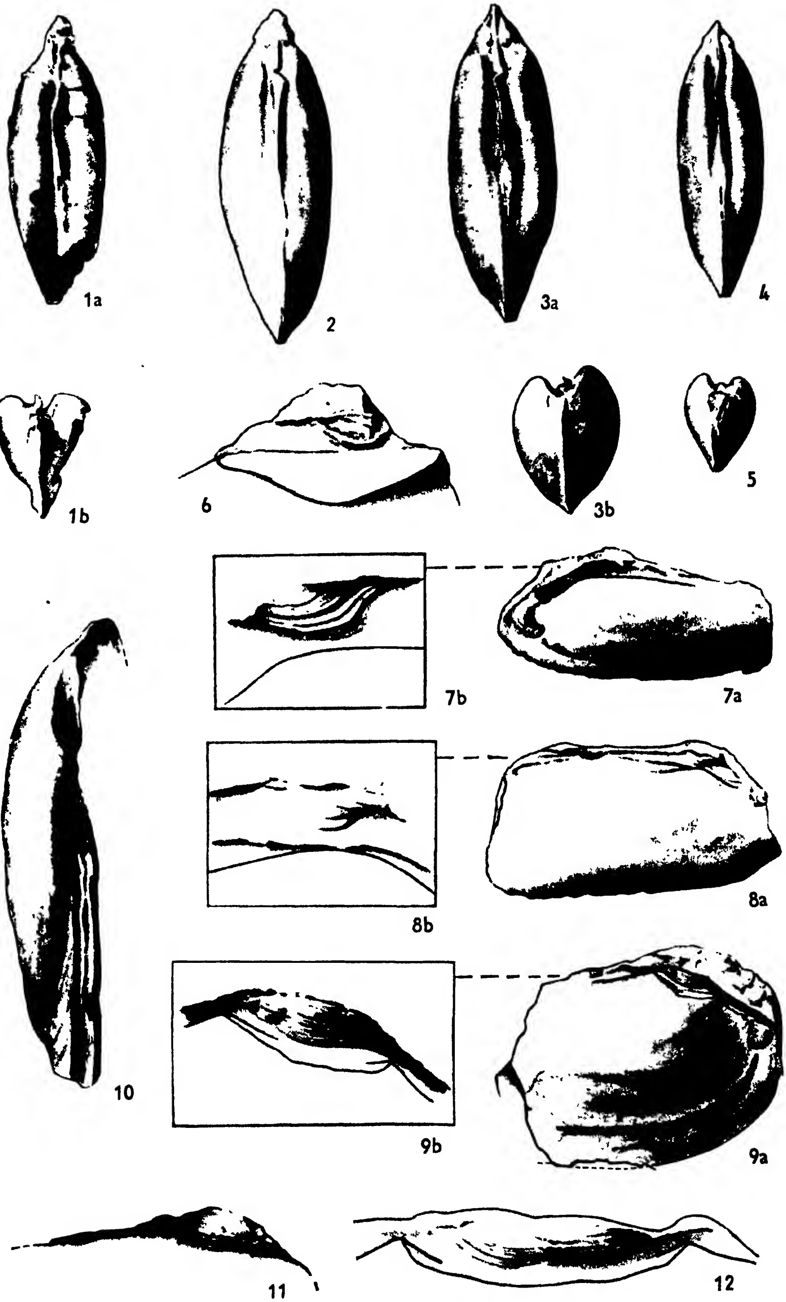
FIG. 3.—Internal mould of *C.* aff. *fallax*, fig. 3A dorsal view, and fig. 3B view from anterior end. The lateral view is shown in text-fig. 7B. Figured Wright, 1934*b*, p. 27, fig. 3K. From Windle. × 1·5. Geol. Surv. Coll. No. 53022.

FIG. 4.—Internal mould of *C.* cf. *fallax*, dorsal view. The lateral view is shown in text-fig. 7C. Figured Wright, 1934*b*, p. 29, fig. 6B. From Windle. × 1·5. Geol. Surv. Coll. No. 53042.

FIG. 5.—Internal mould of *C.* aff. *fallax* (small) viewed from the anterior end. From Hazlehead. × 2. Hunterian Museum, No. S. 13087.



HINGE PLATES OF *CARBONICOLA*.



HINGE FEATURES OF *CARBONICOLA*.

FIG. 6.—Mould of a portion of the hinge plate of *C. haberghamensis* W. B. Wright. The top of the mould of the umbo has been removed. From Honley, 19 ft. 9 in. to 20 ft. above the Soft Bed Coal. × 2. Hunterian Museum, No. S. 12829.

FIG. 7A.—Internal mould of *C.* aff. *fallax* (small) from Hazlehead. × 2. Fig. 7B shows an enlargement of a portion of the hinge plate mould in the umbonal region. × 10. Hunterian Museum, No. S. 13088.

FIG. 8A.—Internal mould of an Anthracomya-like shell, provisionally termed *Anthracomya* sp. From Honley 24 ft. 3 in. above the Soft Bed Coal. × 2. Fig. 8B shows an enlargement of a portion of the hinge plate mould in the umbonal region. × 8. Hunterian Museum, No. S. 12892.

FIG. 9A.—Internal mould of *C. haberghamensis*, anterior end. From Honley, 19 ft. 9 in. to 20 ft. above the Soft Bed Coal. Natural size. Fig. 9B shows an enlargement of the hinge plate mould in the region of the umbo, the upper part of which has been removed. × 2·5. Hunterian Museum, No. S. 12793.

FIG. 10.—Shell of *C.* aff. *protea*, dorsal view. From a bore-hole at Fairweather Green, near Bradford (Hudson and Dunnington, 1939), 4–5 feet above the Soft Bed Coal. × 2. Serial number 291. Collection of Leeds University Geol. Dept.

FIG. 11.—Mould of the hinge plate of *C.* aff. *fallax*, lateral view, in which the umbo has been removed. From Honley, 20 feet above the Soft Bed Coal. × 2. Hunterian Museum, No. S. 12800D.

FIG. 12.—Mould of the hinge plate of *C. haberghamensis*, lateral view, in which part of the umbonal mould has been removed, the lower part being drawn in. From Honley, 20 ft. above the Soft Bed Coal. × 4. Hunterian Museum, No. S. 12778.

Some Grits and Associated Rocks in the Etruria Marls of North Staffordshire

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Introduction

The Etruria Marls, in the Upper Coal Measures of North Staffordshire, lie between the Black Band and Newcastle Groups ; similar marls, which may be variously named, are associated with some other British coalfields and there is evidence that they may rest unconformably beneath the Newcastle Group or its equivalents. The possible existence of this unconformity would be worthy of closer study in North Staffordshire, but it has not been specifically considered in the present work ; further, there has been a recent suggestion that the Etruria Marls may be a diachronic formation (G. H. Mitchell, 1942). Moreover, beds of Etruria Marl facies are known at horizons below this group in several coalfields.

The term " Etruria Marls " was introduced by Gibson (1899) because of the striking development of these rocks in the Etruria region of Stoke-on-Trent where many quarries (" marl holes ") provide excellent exposures. Boulton (1916–17) noted that the rocks are not marls in the petrographic sense, i.e. calcareous clays. Samples examined by the writer consist of ferruginous argillaceous matter, rich in tiny grains of quartz, which somewhat resembles mudstone in hand-specimen and often carries spherulitic rhombohedral carbonate ; " marl " is a common term in North Staffordshire for any locally won clay.

Robertson (1931) gives a useful bibliography of the Etruria Marls and, in the same paper, supports the opinion which he had already foreshadowed (in Hallimond, 1925, p. 88), that the Marls possess distinctive characteristics which are to be ascribed to partial derivation from the decomposition products of the basic igneous rocks associated with the Carboniferous of the Midlands. That decomposed basic rocks appear in the Marls has been recognized, but their quantitative importance has been disputed ; Robertson (1931, p. 22) is content to suggest that they do not usually constitute over 30 per cent of the material.

Among those who have expressed some scepticism concerning Robertson's ideas are Boulton (Robertson, 1931, p. 28), Eastwood (*ibid.*, p. 26), Scott (1932–3), and Wills (1935, p. 231). The validity of these ideas is closely linked with Pocock's belief (1931) that many basic rocks in the Carboniferous of the Midlands are extrusive ; they would thus be available, possibly over wide areas, for immediate denudation with concomitant contribution to the Etruria Marls. Marshall (1942), however, has recently reversed some of Pocock's field observations and reiterated the claim that many occurrences are intrusive. Essentially, Robertson's case must rest on the possibility of demonstrating that the basic rocks, whether intrusive or extrusive, were weathered in Carboniferous times.

The original motive of the present inquiry was the detailed examination of the Etruria Marls of North Staffordshire for assessment of Robertson's hypothesis and scrutiny of present and potential exploitation of these

rocks by the local clay industries ; the exigencies of research of national importance, followed by the author's removal to South Africa, have prevented the following of this programme. The present paper sets out some data, obtained when the study was initiated, concerning the espley rocks ; the account makes no claims to completeness as only the more important of the many exposures have been visited.

THE GRITS AND CONGLOMERATES

Intercalated in the argillaceous material of the Etruria Marls are impersistent grits and conglomerates, often of a typical greenish hue (espley rocks). The green colour is attributed by Boulton (1916–17, p. 249) partly to the presence of chlorite and epidote ; epidote has not, however, been found by the writer. The espley rocks have received a certain amount of attention in the literature, but no detailed study of them has appeared ; those found in North Staffordshire have, in particular, been scantily described. Because of the possibility of recognizing the source rocks of their clastic material, the espley types may indicate the older rocks which contributed to the formation of the Etruria Marl Group as a whole. Much of this group is represented by fine-grained material less amenable to study ; admittedly this material may represent rocks less capable of survival than those seen in the grits and conglomerates.

Some early investigators were impressed by the amount of igneous material in the espley rocks of various districts and, indeed, Jukes mapped some of these rocks as pyroclastics (Pocock, 1931, p. 9). Barrow (Gibson, 1901, p. 265) was uncertain whether the grits in the Etruria Marls were true ashes or comminuted lavas and, in a grit from the High Carr Tileries, North Staffordshire, he (Barrow, in Gibson, 1905, p. 131) recognized quartz crystals with an adhering rhyolitic matrix, fine pegmatitic material, a few fragments of moderately basic igneous rock, and abundant quartz to which, because of its form, he ascribed an igneous origin (it is shown later that this crystal form is determined by regrowth in place). The existence of much quartzose detritus in the espley rocks has been generally noticed. Thus Robertson (1931, plate ii, fig. 3) figures a grit from North Staffordshire containing quartz and quartzite, with acid and basic rocks including a fragment of basalt. Eastwood (Robertson, 1931, pp. 17–19) found occasional dioritic fragments in the espley rocks of South Staffordshire, but the majority of the larger fragments both here and in Warwickshire were of quartzite (including the Lickey type), vein-quartz, siliceous sandstone, and green shale. A similar assemblage of rock fragments is mentioned by various workers in the Memoirs of the Geological Survey on the Southern Part of the South Staffordshire Coalfield (1927), the Country around Birmingham (1925), and the Country around Coventry (1923) ; in the first two of the Memoirs cited, tuffs are also recorded. Similarly, Boulton (Robertson, 1931, p. 28) speaks of fragments of Lickey Quartzite or Llandovery Sandstone type, and of vein-quartz, with acid and basic rocks including ashes.

THE ESPLEY ROCKS IN THE FIELD

These rocks were examined in the quarries of Basford and Etruria

which are at or near the junction between the Marls and the overlying Newcastle Group, in those of the Chesterton area which exhibit the Marls not only at this horizon but throughout much of their vertical thickness, and, lastly, in those along a line extending from Newcastle-under-Lyme through Trent Vale to Blurton where the middle and summit of the Marls are seen. The grit bands are often only a few inches thick, but may attain at least 6 feet; the thicker beds are usually split by argillaceous partings. The bands as a whole are markedly impersistent, but thick examples in the Chesterton area have sufficient lateral extent to cause features which can be traced for some distance on the ground (cf. Gibson, 1905, p. 131).

Megascopically most of the espley rocks appear as rather fine-grained grits, often of a dull green, blue-green, yellow-brown, or brownish colour. The last two colours are sometimes superficial and result from the weathering of green grits, but they may be shown by fresh material. The grits, including the greenish type, manifest occasional current-bedding. Dendritic growths of a black oxide of manganese are sometimes obvious on the paler rocks; highly weathered grits may be blackened by this oxide. Some rocks are spattered by pyrite, especially along joints; an aberrant pyritic grit is described later. It has not been possible to decide if any pyrite is of metasomatic origin; this possibility was considered because of the post-Carboniferous igneous activity in the district (see especially Scott in Gibson, 1925, p. 86).

Certain grits are unusually coarse and finally pass into conglomerates, e.g. in the Etruria area as previously recorded (Gibson, 1905, pp. 52–3; 1925, p. 45); special attention was devoted to these conglomeratic espley rocks, which are rather rare in North Staffordshire.

The Espley Rocks in Thin Section

The various bands show no apparent differences in the nature of their contained fragments though the finer grits tend to be richer in the more siliceous detritus; the cementing materials, however, exhibit some variation. A particular bed is described in detail as it exemplifies the green variety of espley rock; notes are then appended on some other types. The bed, which is only a few inches thick, appears in the lower part of the quarry (almost certainly the pit showing faulting mentioned by Gibson, 1905, p. 122) of the Trent Vale Brick and Tile Co., Ltd., at the end opposite to the brickworks. It shows normal graded bedding; at the base is a fine conglomerate which is followed, successively upwards, by coarse and then by fine grit. The band has been examined microscopically, chemically, and by X-ray powder-photography; for the purpose of microscopical description both conglomerate and grits will be considered together as they differ only in the size of the clastic material and in the increased number of quartzose fragments to be found in the finer portions of the bed.

The Clastic Fragments

These are principally quartz as single or composite grains of which the shape has been modified by movement of silica within the rock. The grains demonstrate this migration by exhibiting :—

(1) corrosion ;
(2) the welding of individuals along narrow necks ;
(3) rims of secondary quartz ;
(4) crystal faces ;

not all the features are of course observable in the same grain, but it is possible that some grains have suffered cycles of alternating corrosion and redeposition. The phenomena are curiously sporadic and, even where rounded and angular grains are found in close proximity, there is no certainty that either character is original ; the rounding may be indicative of corrosion and the angularity of regrowth. It is demonstrable that some grains have become sharper through deposition of silica, even where definite crystal faces are not manifest.

The quartz fragments have suffered also from penetration by calcitic veinlets from the matrix which may terminate in cracks along which the invasive material would appear to have been forcing its way.

Some of the quartz is of sedimentary origin ; this is revealed by the occurrence of rocks containing quartz grains set in a silica cement and resembling the Cambrian quartzites of Hartshill or Lickey. There are also fragments with angular quartz, a green cement, and occasional flakes of a green pleochroic mica ; these strikingly resemble a rock from breccia in the Stratford borehole, described by Shotton (1929, pp. 190 and 194) and matched by him with a Lickey type. Pieces of shale provide a further sedimentary record.

Quartz has been contributed also by metamorphic rocks ; this is shown by the presence of fragments wherein the quartz veins are elongated in a common direction and are sometimes even ribbon-like. The rocks could be termed quartz-schists, but at least some of them may represent the quartzose layers that once interleaved the micaceous felts of gneisses ; this is indicated by the rare occurrence of parallel shreds of muscovite between the quartz units and, more strikingly, by the appearance in one example of a muscovite book which has its maximum extent in the direction of elongation of the quartz.

Quartz occurs also as composite fragments, built of intricately suturing grains, which resemble vein-quartz. That this ascription is incorrect in some instances is shown by the appearance of schistosity in limited areas of some of the fragments. Intricate suturing sometimes characterizes the quartz of metamorphic terraines where crystalline regrowth has proceeded, e.g. in the injection complex in Perthshire familiar to the writer (Williamson, 1935, e.g., p. 387, para. 2) or in those of Central Sutherland (Read, 1931, pp. 112–15 ; on pp. 114 and 158 the resemblance of certain quartzites to vein-quartz is specifically mentioned). An association of quartz and chalcedony, however, suggests that some material is derived from silica-veins or from amygdales in lava.

There are scarce pieces of rather acid felspar with twinning of plagioclase or of vague microcline type ; these may be of metamorphic parentage as no plutonic rocks have been identified. Hypabyssal rocks are represented by a granophyre with chloritized felspar (cf. Barrow in Gibson, 1905, p. 131), but the bulk of the igneous material is of volcanic origin and exemplified by the following occurrences :—

(1) A groundmass of quartz and chloritic matter holds a corroded phenocryst of quartz as well as calcite pseudomorphs after unidentified minerals which may have included felspar. The rock appears to be a rhyolite (or, more doubtfully, a quartz-felsite); Barrow (*op. cit.*) noted similar rocks. A second fragment shows a chlorite flake that may represent biotite while, in a third, former biotite is again suggested, but the felspar phenocrysts are partially preserved; some appear to be orthoclase.

(2) Felspar laths, up to about 0·1 mm. long, apparently a rather acid plagioclase, show marked flow parallelism and are surrounded and invaded by a structureless green product; there are tiny patches and veins of quartz. Phenocrysts are lacking; the fragment is probably the groundmass of an andesitic lava.

(3) A lithic tuff has small quartzose fragments, with some associated felspar, in a brown ferruginous base; the fragments somewhat resemble the lava described under (2). There are also indeterminate chloritized masses.

(4) A vitric tuff has been completely silicified, but the shapes of the glass shards are marked out by areas of unusually coarse quartz.

The Cement

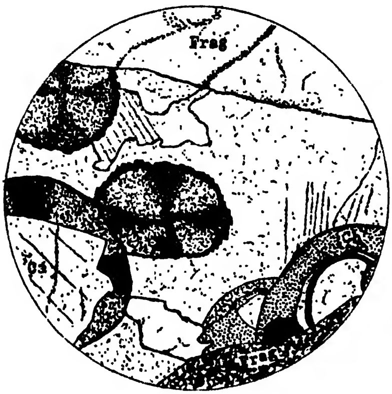
The matrix of the clastic fragments occupies a considerable volume and consists of rhombohedral carbonates and of a green mineral shown later to be chamosite (the " serpentinous material " of Barrow in Gibson, 1905, p. 131). Dixon has already suggested that chamosite may be more widespread in the sediments of the Midlands than records show (Fleet, 1925, p. 126).

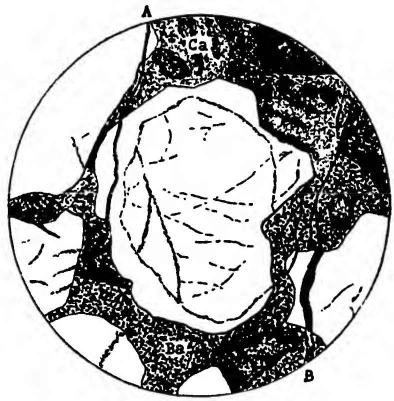
The analysis given below (Table I) implies that, while calcium is abundant in the carbonates, magnesium and manganese are also present; some sideritic carbonate is discernible in slice and revealed by X-ray powder photography. It cannot be precisely ascertained how the $CaCO_3$, $MgCO_3$, $MnCO_3$, and $FeCO_3$ molecules are housed in the crystalline phases. Most of the carbonate is colourless or greyish and forms homogeneous crystals of very varying size which are sometimes complexly interlocked along their boundaries. These enclose spherulites, up to 1·5 mm. in apparent diameter, without detectable nuclei, which are formed of similar carbonate; they show the usual N.–S. relief brush, extinction cross, and negative elongation of the fibres, i.e. along the c-axis. The fibres are visible only under high magnifications.

Some spherulites, when examined with a low powered objective between crossed nicols, without the use of the converging system, show what is substantially a negative uniaxial figure; the extinction cross associates with a series of circular colour bands in which the successive orders of Newton's scale follow one another concentrically outwards. This phenomenon has long been known but was recently reinvestigated and figured (Morse, Warren, and Donnay, 1932; Morse and Donnay, 1932 and 1936).

The fibres of the spherulites are often cut across by a wide zone of non-fibrous carbonate grains. This zone may be roughly concentric with the outside of the spherulite; alternatively a single large crystal of carbonate may replace the centre of the host (Text-fig. 1). The non-

fibrous carbonate often presents a series of zigzag boundaries to the enclosing spherulite which would appear to represent an attempted development of crystal-faces ; the spherulites may be reduced to a mere fringe about the internally disposed carbonate. That this carbonate is secondary scarcely admits of dispute, especially when it is found that carbonate internal and external to the spherulite has sometimes a common orientation and is doubtless confluent at some point outside the plane of the thin section.





TEXT-FIG. 1.—Conglomerate from the Trent Vale band. Camera lucida drawing in ordinary light with extinction crosses added to indicate spherulitic structures (otherwise invisible except under high magnifications). Three calcitic spherulites are edged by siderite granules which may have rhombohedral outlines ; the siderite border is more distinct in two of the spherulites. The third spherulite is replaced at the centre by a large crystal of calcite (Ca) which tends to show crystal-form. All three are set in a matrix of calcite which is largely one discrete crystal ; the most central of the three gives a false impression of erosion.

A chamosite oolith has concentric zones of chamosite (Ch) and calcite. This oolith, and one of the spherulites, are truncated by clastic fragments (Frag.).

(Diam. of field, 1 mm.)

TEXT-FIG. 2.—Grit from the Etruria region. Camera lucida drawing in ordinary light. A quartz-grain has a growth of secondary quartz which exhibits crystal-faces. A calcitic vein can be traced from A through a quartz-fragment, whence it crosses the cement and traverses the growth of secondary silica just mentioned ; a second vein can be followed from B and cuts a grain of clastic quartz. The cement includes calcite (Ca) and barytes (Ba).

(Diam. of field, 1 mm.)

Similarly, the corrosion of some small spherulites held by homogeneous carbonate crystals is thought to depend on solution, followed by recrystallization which allows the host crystal to encroach on the spherulites. Initially, some of these spherulites give the impression of an erosion pre-dating their existence in the conglomerate.

Spherulitic carbonates showing signs of erosion, and sometimes of subsequent repair, have, however, been found in the argillaceous facies of the Etruria Marls.

Small orange-brown sideritic crystals occur in the dominant pale carbonate. They have a tendency to rhombohedral outline, but between crossed nicols may show a single diffuse brush. Good spherulitic structure is rare. They may, however, adopt an annular habit in which the grains are arranged about patches of clear carbonate which may, or may not, be of spherulitic type (Text-fig. 1). The siderite appears to be of late formation and may depend upon the occurrence of decomposition processes in the clastic fragments and the chamosite.

The chamosite in the cement tends to lack definite structure, but occasionally forms flakes with a poor cleavage which allows the determination of the pleochroic scheme :—

fast (perpendicular to cleavage) = pale green with hint of yellow
slow (parallel to cleavage) = darker green.

A patchy brown colour is sometimes apparent ; this appears to result from incipient alteration and not to represent a second type of chlorite.

The mineral is isotropic or polarizes in first order greys, but the extinction is apt to be irregular and suggests a minutely fibrous texture.

The chamosite may be involved in various concentric structures. Thus a mosaic of large grains of clear carbonate carries an annulus stained green by minute chloritic flecks ; in a second example this annulus has a solid median band of isotropic chamosite and is held by a single crystal of clear carbonate fringed by sideritic grains with a fibrously radiate texture. The chloritic shells are sometimes duplicated (Text-fig. 1).

Another type of concentric structure involves more or less solid chlorite with alternating green and brownish-green zones. The darker zones are isotropic, while the green annuli, though lacking visible structure, show sections of the arms of an extinction cross. The repetition of greenish and brownish zones recalls phenomena noted in chamosite ooliths by Pulfrey (1933, p. 404) ; well-developed chamosite ooliths are not, however, found.

The various spherulitic and concentric structures described above are rarely complete but are truncated by the clastic fragments ; they have undoubtedly developed in place (Text-fig. 1).

The existence of these structures in the Etruria Marls has been previously recorded, though attention has been directed to the argillaceous facies rather than the espley rocks. Thus Gibson (1905, p. 226) noted the sideritic spherules in this facies, while Spencer (1925, p. 676) analysed them. Hallimond (1925, pp. 87–8) described calcite pisoliths in a barytes bed and in the associated marl from North Staffordshire ; these pisoliths had radial structure. He mentioned also pisolitic limonite from South Staffordshire. Fleet (in Pulfrey, 1933, p. 430) suggested an examination of the Etruria Marls of South Staffordshire and their associated espley rocks as these deposits had chloritic matter and pisolitic bodies which appeared to have analogies with the Welsh material described by Pulfrey.

The Chloritic Mineral in the Cement

The fine grit from the top of the Trent Vale band of espley rock just described was investigated by the Geochemical Laboratories (of Alperton, Middlesex) in a manner similar to that outlined by Ennos and Sutcliffe

(in Hallimond, 1925, pp. 115–120) and the composition of the extractable portion evaluated in the usual way (Table I). The formula obtained for the chlorite is 264 RO.117 R_2O_3.200 SiO_2 as compared with the 300 RO.100 R_2O_3.200 SiO_2 of theoretical chamosite. If we assume that Fe_2O_3 represents iron which was oxidized subsequently to the formation of the chlorite, the formula becomes 292 RO.103 R_2O_3.200 SiO_2; the complete validity of this inference is very doubtful. The molecular proportions of RO might be depressed against those of R_2O_3 and SiO_2 by the existence of acid soluble clayey matter (cf. Hallimond in discussion on Pulfrey, 1933, p. 428), especially if such material had the $R_2O_3 : SiO_2$ ratio of 1 : 2 common to both chamosite and some clay minerals. It should also be noted that manganese is assumed to be absent from the chamosite, and siderite from the cement; the incorrectness of the latter hypothesis is revealed by microscopical and X-ray examination.

TABLE I

Insoluble residue	68·94		$Ca_3(PO_4)_2$	0·06
SiO_2	4·77		$CaSO_4$	0·07
Al_2O_3	4·17		$CaCO_3$	5·48
Fe_2O_3	0·88		$MnCO_3$	1·77
FeO	6·86		$MgCO_3$	1·75
MgO	1·22		Remaining oxides	17·12
CaO	3·13			
TiO_2	0·05		SiO_2	200
P_2O_5	0·03	R_2O_3	Al_2O_3	103
MnO	1·09		Fe_2O_3	14
CO_2	4·01	RO	FeO	240
SO_3 (acid soluble)	0·04		MgO	24
	95·19			

Mr. F. A. Bannister kindly examined, by X-ray powder photography, a concentrate of chlorite from the matrix of the conglomerate in the Trent Vale band; calcite, siderite, and considerable quartz were still present in this concentrate. The latter mineral caused difficulty, but, as far as they were determinable, the spacings ascribed to the chlorite agreed fairly well with those published for chamosite (Bannister in Hallimond, 1939, p. 462).

In the writer's opinion the chemical and X-ray evidence, taken together, are adequate to establish the presence of chamosite.

A Note on the Origin of the Cement

Extensive replacement of the fibrous carbonate by large crystals has been demonstrated; this implies a reduction in specific surface of the type which normally occurs when crystals are in contact with too small a quantity of a liquid phase to dissolve them completely. We may assume that the cement was initially finer-grained than at present; probably it was a gel-like mass of carbonate and clayey matter which became modified in structure as the spherulitic and concentric growths developed in it. In the Trent Vale band the cement occupies a considerable volume and accompanies both coarse and fine detritus; this suggests contemporaneous deposition of both detritus and cement-forming material

where the latter was probably in a flocculated condition (cf. Woodland, 1938, p. 453). An alternative hypothesis would consider the sweeping of detritus, by surface currents, over still water beneath which lay a bed of (preferably thixotropic) colloidal clay-carbonate mixture ; grading of fragments might then occur during settling and yield the observed grain-size variation in the band. Against this idea is the appearance of current-bedding in chamosite-carbonate grits at, e.g. Chesterton.

The Espley Rocks from Other Localities

These do not differ from the Trent Vale examples in the nature of their clastic fragments and the migration of silica is again apparent (Text-fig. 2) ; a devitrified flow-banded lava (probably rhyolite) and rare flakes of muscovite, however, provide further records. In addition to the chamosite-carbonate association described, the cementing materials involve various combinations of chamosite, carbonates, barytes, and ferruginous clayey matter. Barytes is often deep brown in thin section from included impurities ; its presence has been confirmed in the crushed rocks. Streaks of ferruginous clay mark the current-bedding seen in certain grits and they may associate with trails of black iron-ores and worn zircons. The clay is probably redeposited material from the argillaceous facies of the Etruria Marls, as one current-bedded rock includes a fragment of typical Etruria " marl ". Apart from carbonate veins which enter the clastic fragments from the matrix, there are other veins which cut both fragments and matrix (Text-fig. 2) ; these contain carbonate or barytes individually or together. Pink dialogite, visible megascopically, forms part of some of the veins.

An exceptional rock-type occurs as a band a foot thick, in the Metallic Tile Company's quarry at Chesterton, a few feet below the base of the Newcastle Group. It consists of closely compacted quartz fragments varying from 0·3 mm. across down to minute chips ; no cement is detectable. Stringers of barytes traverse this quartzite and there is much authigenic pyrite, often euhedral. The pyrite partially replaces the quartz grains in the manner seen in the banket (cf. du Toit, 1939, plate iv, fig. 3).

The Heavy Minerals of the Espley Rocks

For many samples treatment with dilute hydrochloric acid was a necessary precursor to bromoform separation.

The minerals identified were, in approximate order of abundance : iron-ores (ilmenite and magnetite), zircon, tourmaline, rutile, garnet, staurolite, anatase, and green spinel. Sphene is probably present ; brookite has been proved ; abundant barytes is released from the cement of some rocks. There is a local richness in pyrite (sometimes with chalcopyrite). This list is almost identical with that established by Fleet (1925) for the sandstones and espley rocks in the Old Hill Marls (= Etruria Marls) of a more southerly part of the Midlands, i.e. magnetite, ilmenite, zircon, tourmaline, rutile, garnet, anatase, apatite, and barytes. Apatite, though it would not survive the acid treatment mentioned above, has not been found in the few untreated samples examined. Fleet, however, did not obtain staurolite from horizons in the Carboniferous sequence below the Halesowen Sandstone (= Newcastle Group).

The notes on mineral species which follow have been supplemented by the examination of thin sections :—

Opaque Minerals.—These are ilmenite, magnetite, pyrite, and chalcopyrite ; ilmenite and magnetite easily preponderate, and in most, perhaps all, samples ilmenite is the more abundant. Ilmenite is shapeless ; in the matrix of the Trent Vale conglomerate it shows "geometrical" alteration to leucoxene, associated with anatase. Magnetite is rarely euhedral ; there is a possibility that a small proportion is authigenic.

Pyrite is seen as broken fragments, often derived from aggregated cubes or pyritohedra. Chalcopyrite is occasional and may be intergrown with pyrite ; in one sample, untreated by acid, it associates with azurite. These minerals are authigenic.

Zircon.—Most grains are prismatic but worn ; many, however, are sharply euhedral and show the usual forms. The volcanic detritus could yield these euhedral grains. There are zircons with zoning and with inclusions which are not detailed here. Well-rounded grains exist, of which some are colourless while others are of the familiar purple type ; there are numerous records of the characteristic roundness of this type (Woodland, 1938, p. 452 and refs. cit.).

Tourmaline.—There are all transitions from eumorphic to ovoid or rounded grains. The eumorphic types are prismatic, but have usually lost their terminations by fracture ; concomitantly, cleavage fragments appear. The colour involves yellow, brown, green, and blue, usually in some combination which gives intermediate tints. A common type has X = faint yellow-brown ; Z = bluish green or greenish brown. Rarely X has a pinkish tinge associated with the brown ; Z is sometimes brown but very rarely a pure green or pure blue. Patchy or zonal arrangements of colour are seen in favourable examples.

Interest centres on the eumorphic grains ; these may have evolved by growth or regrowth in place. It is significant, however, that the Trent Vale conglomerate contains minute tourmaline crystals in a fragment of elongated metamorphic quartz. If such quartz was part of a gneiss it is conceivable that it formerly associated with micaceous felts carrying well-formed tourmaline (cf. the Dalradian occurrences described by Williamson, 1935).

Rutile.—There are prisms, more or less abraded, and occasional knee-shaped twins ; many grains are irregular though rarely well-rounded. Yellow or yellow brown types are commoner than brown or reddish brown.

Sphene (?).—Worn brownish grains are not uncommon, but yield only a hazy interference figure.

Garnet.—Colourless, yellow-brown, or pinkish anhedra, of which some may have originated as cleavage-flakes, often show surface patterning ; such patterned grains have been obtained from rocks where no acid treatment was employed. It is impossible to decide if the garnets are directly derivative from metamorphic rocks and have been etched in their present environment.

Anatase.—The mineral appears as faintly brown basal tablets, slightly biaxial, and often associates with leucoxenized ilmenite ; there are no certainly detrital grains.

Staurolite.—This is yellow or yellow-brown and may be distinctly pleochroic ; usually it is irregular, but rarely it shows the " angular " form figured by Thomas (1909, plate xii, fig. 4*c*).

Spinel.—About six allotriomorphic grains have been identified as green spinel. They are appreciably thick and almost opaque, but transmit a deep green if strongly illuminated. The refractive index is high and the grains are non-pleochroic and isotropic.

Brookite.—This may be commoner than is supposed, but the crossed axial dispersion could be verified only for a single irregular brownish grain.

Barytes.—Locally abundant are irregular grains, or lozenge-like forms depending on the operation of the cleavages. Flame tests indicate the presence of a little strontium in some samples..

The Calcareous Bands

Thin bands of limestone are recorded between the Etruria Marls and the Newcastle Group, and in the Marls themselves (Gibson, 1905, 1925) ; three examples have been examined.

A black limestone from an 8-in. band at the base of the Newcastle Group in the Metallic Tile Company's quarry at Chesterton, shows, in slice, numerous minute quartz-fragments in a minutely granular, almost cryptocrystalline calcitic base. There are occasional sections of Spirorbis. Black dendrites witness the occurrence of the $MnCO_3$ molecule.

In the same quarry is a thin layer of purplish rock, with blackish alteration, carrying Spirorbis and Ostracods (kindly identified by Mr. T. H. Withers) ; the layer may represent the line of calcareous nodules, containing Spirorbis, which Gibson (1905, p. 130) mentions as occurring some 80 feet below the summit of the Etruria Marls in this quarry. Microscopically the rock resembles that just described, but carbonate spherulites appear in areas embraced by fossil shells. There are some vaguely pisolitic bodies in the weathered part of the rock, but no structures in the fresh material which compare with the spheroidal bodies recently described by Woodland (1939). A partial analysis of the fresh rock has been made by the Geochemical Laboratories (Table II).

TABLE II

SiO_2	11·31
Al_2O_3	3·44
Fe_2O_3	3·43
FeO	0·91
TiO_2	0·18
MnO	4·42
MgO	2·10
CaO	37·51
CO_2	33·94
	97·24

A band at Blurton, marked on the Geological Survey's 6 in. map as the limestone at the base of the Newcastle Group, appears transitional towards a gritty espley rock. It is flaggy and yellow-brown, with silicification along the joint-planes and many manganiferous dendrites. Angular

detrital quartz is more abundant, and coarser than in the limestones just described. Many shell fragments still appear, some probably representing Spirorbis. Organic structures have not been recognized in the espley rocks proper.

Discussion

The clastic fragments in the espley rocks could be derived from a Pre-Cambrian complex where rather siliceous gneisses and schists are associated with volcanic materials; quartzites and shales (probably Cambrian) have also contributed. The rock assemblage resembles that listed by Shotton (1929, p. 190) for the Gibbet Hill conglomerate and Kenilworth Breccias. Rocks of the requisite types are found in Central England, though tourmaline-bearing schists or gneisses, the existence of which was postulated above, do not seem to be recorded in this area.

The heavy mineral suite is in keeping with the observed detritus and cementing materials, and includes nothing suggestive of a quota from basic rocks (ilmenite and magnetite lack diagnostic value). The absence of epidote is striking; this absence was noted also by Shotton (1929) in his material and used as an argument against derivation from the epidote-rich Nuneaton area; it is, however, feasible that epidote may have been selectively destroyed in the sediments.

Arguments as to near or far derivation of material, based on the angularity or rounding of the grains, are largely frustrated by the evidence of a former mobility of silica within the rocks; we hesitate to designate any particular area of observable rocks as the source of the clastic material here studied.

Basaltic debris has not been unequivocally identified and, if Robertson's hypothesis (1931) is correct, basic material may be represented by the manganese, magnesium, and iron of the cement rather than among the clastic fragments themselves. It is interesting to note that chamositic chlorite associates with the decomposed basalts in the Millstone Grit of Ayrshire (Wilson, 1930, p. 210; Eyles, 1930, p. 67).

Summary

The grits and conglomerates in the Etruria Marls of North Staffordshire include types with a chamosite-rhombohedral carbonate cement containing interesting spherulitic and concentric structures. Manganese appears in this cement and in certain calcareous bands in the argillaceous facies of the Marls. The clastic fragments suggest derivation from Pre-Cambrian and Cambrian rocks. The heavy mineral suite resembles that listed by Fleet for similar horizons in the Midlands, but staurolite is recorded also.

There is no new evidence bearing on Robertson's hypothesis that basic igneous rocks of Carboniferous age have contributed to the formation of the Etruria Marls.

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North Staffordshire Technical College, where rock-sections illustrative of this paper have been housed. Dr. G. F. Claringbull kindly undertook the proof-reading in the author's absence abroad.

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Caldenocrinus gen. nov. and related Scottish Crinoids

By James Wright

(PLATES III and IV)

THE new genus here proposed is based on nine specimens. All are more or less complete crowns. The best preserved example (Plate III, figs. 1, 2, 3, 5) was previously illustrated in *Trans. Roy. Soc. Edin.* as *Synerocrinus incurvus* (Trautschold) (Wright, 1939–1940, pl. xi, fig. 8). Later, the discovery of another well-preserved specimen caused some doubt about this interpretation and led to further cleaning and developing not only of the first mentioned specimen, but of others in my collection. Some of these were labelled as *Synerocrinus incurvus* (Trautschold) or the kindred species *Amphicrinus scoticus* Springer. From a study of all these specimens it is now evident that we are here dealing with a crinoid which differs in certain aspects from *Synerocrinus* or in fact from any other described Ichthyocrinid. Two specimens previously figured as *Amphicrinus scoticus* Springer (Wright, 1914, pl. xix, fig. 4, 1939–1940, pl. xi, fig. 2) are now here referred to the new genus.

Moore and Plummer (1940) have pointed out that the specimens described as *Forbesiocrinus incurvus* by Trautschold (1867, 1879), subsequently transferred to *Synerocrinus* by Jaekel (1897) and dealt with in greater detail by Springer (1920) under *Synerocrinus incurvus* really consist of two different types, one having isotomous arms and the other heterotomous arms. The first specimen figured by Trautschold has isotomous arms, and specimens of this type are now restricted by Moore and Plummer to *Synerocrinus incurvus* whereas those with heterotomous arms are transferred to a new genus *Talanterocrinus* with *T. jaekeli* M. and P. as the genotype species.

In *The Crinoidea Flexibilia* (1920, pl. lxxv, figs. 12, 13), Springer illustrates two Fife specimens from my collection. One is from Roscobie, the other from Ardross, and both are referred to *Synerocrinus incurvus*. For reasons to be noted later, the Roscobie example probably belongs to *Caldenocrinus*, the new genus here described ; but the Ardross specimen clearly belongs to *Talanterocrinus jaekeli* Moore and Plummer. The same authors (1940) also describe a new species of *Synerocrinus* (*S. formosus*) from the Pennsylvanian of the United States, but on the basis of the new interpretation of the genus no crinoids so far found in the Scottish Carboniferous can be referred with certainty to it. Some cups and basal parts were at one time considered to belong to *Synerocrinus* but are now here placed under *Talanterocrinus* and named *T. strimplei* in honour of Mr. Harrell L. Strimple, of Bartlesville, Oklahoma, a well known student of crinoids in the United States.

Ichthyocrinidae Angelin

Caldenocrinus gen. nov.

An Ichthyocrinid with short rounded crown and rather flat base ; IBB entirely within ring of BB ; BB, with exception of post. B, usually completely covered by column ; column socket moderately deep ; lumen

pentalobate ; columnals fairly equal in thickness and strongly crenulated at edges ; post. B rather long, often extending beyond RR and followed by three plates in a single series, all fitting closely to adjoining BrBr ; PBrBr two ; SBrBr two or three ; IBrBr few, from three to six or seven plates, the first IBr being followed by one or two double rows ; ISBrBr usually limited to one hexagonal plate ; arms heterotomous, in twenty main branches ; plates thick, smooth, or finely granular.

Genotype.—*Caldenocrinus curtus* sp. nov.

Caldenocrinus curtus sp. nov.

Plate III, figs. 1–5, 14, 17 ; Plate IV, figs. 4, 8, 9.

Forbesiocrinus (*Amphicrinus scoticus* Springer MS.), Wright, 1914, pl. xix, fig. 4.
Amphicrinus scoticus Springer, Wright, 1939–40, pl. xi, fig. 2.
Synerocrinus incurvus (Trautschold), Wright, 1939–40, pl. xi, fig. 8.

Holotype.—J. W. Coll. 1088 from Seafield Tower Limestone, Seafield shore, west of Kirkcaldy, Fife. (Plate III, figs. 1, 2, 3, 5.)

Paratypes.—J. W. Coll. 1653 from No. 2 Bed, Invertiel, Fife (Plate III, figs. 14, 17) ; 1633 from No. 1 Bed, Invertiel (Plate III, fig. 4) ; 2214 from No. 1 Bed, Invertiel (Plate IV, fig. 8) ; 2099 from Roscobie (Plate IV, fig. 9).

Dimensions of Holotype.—Extreme height of crown 34·3 mm. ; extreme width of crown 44·9 mm.

Horizon.—Lower Limestone Group (Mississippian).

Remarks.—This being the only species so far found, the generic description given above covers its more important characters. Among all the specimens now referred to it the holotype is the most complete and less crushed than any of the others. The arms are beautifully preserved except on the right lateral side where the distal parts of two rays are missing. The base is well shown (Plate III, figs. 1, 2, 3, 5). As a general rule in most specimens, the basals, with exception of posterior basal which cuts through and often extends beyond the radials, are completely covered by the column. In the holotype, however, and in one or two other specimens, the tips of these basals can just be detected as minute triangles between the radial sutures on the outside edge of the column socket. Following the posterior basal are three plates in a single row, all of which are closely fitted and dovetailed into adjoining brachials. There is no sign in the holotype or in the other specimens that these plates formed part of a tube. The closely fitting anal plates and absence of a tube, combined with the heterotomous arms, are therefore quite distinctive of *Caldenocrinus*. In so far as preserved all the other specimens show the same characters. Paratype No. 1653 (Plate III, figs. 14, 17), is rather crushed, but shows the heterotomous nature of the arms particularly well. On the basal side (Plate III, fig. 17) the cup is much crushed, but a fragment of the proximal end of the column is preerved here and higher up in the photograph a longer portion of the column can be seen. In the fragment near the cup there is no sign of any thickening of the column in the proximal region, but the evidence of this specimen is scanty. Paratype No. 1633 (Plate III, fig. 4) is somewhat squeezed and flattened out on the left lateral side (left of photograph), but shows well the nature of the anal region, interbrachials, intersecundibrachs, etc. Other specimens are similarly preserved and three, including the paratype No. 2214,

show rather more of the arms (Plate IV, fig. 8, top left of photograph). Another paratype No. 2099 shows particularly well the thick nature of the plates and the character of the base generally (Plate IV, fig. 9). The interbrachials in *Caldenocrinus* number about the same as in *Synerocrinus* and *Talanterocrinus*. The first IBr is usually succeeded by two plates in a row. These may be followed by another double row and by one or two smaller plates before the rays meet. These plates are never so numerous as in *Amphicrinus scoticus* where five or six double rows are common. The intersecundibrachs are also less in number, and in *Caldenocrinus* usually consist of one hexagonal plate only.

In separating *Synerocrinus* from *Talanterocrinus*, Moore and Plummer emphasize that Trautschold's original specimen of *S. incurvus*, reproduced by Springer (1920, pl. xlii, fig. 1), has isotomous arms and in this respect does not agree with the other figured specimens which have heterotomous arms. On this ground, therefore, Moore and Plummer seem quite justified in separating this form from the others and retaining it under *S. incurvus*. The same authors also take Springer's figs. *2a* and *2b*, both of which show the character of the base and anal structure, as belonging to the same species. In both figures the large truncated triangular posterior basal is succeeded by a smaller plate followed by a tube. This character, regarded by Springer as on the border line between Ichthyocrinidae and Taxocrinidae, is also common to the other figures referred by Moore and Plummer to *Talanterocrinus*. The nature of the base is not specially mentioned by Moore and Plummer in their discussion of the two genera nor in the description and figures of their new species *Synerocrinus formosus* from the Pennsylvanian (1940, pp. 90–98, pl. 2, figs. 3, 4). If, however, it is correct to regard Springer's figs. *2a* and *2b* as belonging to the same form as Springer's fig. 1, we must infer that *Synerocrinus* and *Talanterocrinus* have the same kind of anal area. In this respect both genera differ completely from *Caldenocrinus*. Another distinction is that in *Synerocrinus* and *Talanterocrinus* considerable portions of the basals are always exhibited well beyond the column; these plates are rarely seen in *Caldenocrinus* outside the column socket walls. For comparison a specimen of *Talanterocrinus jaekeli* Moore and Plummer from Ardross is shown on Plate III, fig. 6. This is the specimen figured by Springer (1920, pl. lxxv, fig. 13) as *Synerocrinus incurvus* (Trautschold). The cup is well preserved and the conspicuous basals, outside the column, can be readily seen in the photograph. The Roscobie specimen figured by Springer (1920, pl. lxxv, fig. 12) also as *Synerocrinus incurvus* probably belongs to *Caldenocrinus curtus*. The base is much crushed, but a careful examination discloses no basals outside the column socket, and the general characters of the base here are the same as in other specimens of *Caldenocrinus curtus*. Another specimen from Roscobie is shown on Plate IV, fig. 9, and is very instructive in this respect. To sum up: although the heterotomous arms of *Caldenocrinus* resemble those of *Talanterocrinus*, the basal and anal characters have more in common with *Amphicrinus* and *Ainacrinus* than with *Synerocrinus* and *Talanterocrinus*. The relationship of these genera may be summarized thus :—

Caldenocrinus agrees with *Amphicrinus* in general characters of base, but differs in anal area and in arms, and has fewer IBrBr and ISBrBr.

Caldenocrinus agrees with *Talanterocrinus* in arms and small number of IBrBr and ISBrBr, but differs in structure of base and anal area.

Caldenocrinus agrees with *Synerocrinus* in small number of IBrBr and ISBrBr, but differs in structure of base and arms.

Caldenocrinus agrees with *Ainacrinus* in anal area, but differs in structure of base and arms, and has greater number of IBrBr.

	Arms	*Anal area*	*IBrBr and ISBrBr*	*Basals, excepting post. B*
Caldenocrinus	heterotomous	single plates, no tube	few	rarely visible outside column
Synerocrinus	isotomous, not interlocking	few plates and tube	few	visible outside column
Talanterocrinus	heterotomous	few plates and tube	few	visible outside column
Amphicrinus .	isotomous, interlocking	single or double series, no tube	numerous	not visible outside column
Ainacrinus .	isotomous, divergent	single plates, no tube	few	visible outside column

Talanterocrinus strimplei sp. nov.

Plate III, figs. 8, 9, 13, 15, 16.

A small species with rounded base ; post. B elongate, usually extending well beyond RR ; considerable portions of BB always visible outside column socket ; plates smooth or finely frosted.

Holotype.—J. W. Coll. 2057*a* from No. 1 Bed, Invertiel (Plate III, fig. 9).

Paratypes.—J. W. Coll. 2057*b–g* from same locality.

Horizon.—Lower Limestone Group (Mississippian).

Remarks.—This species is based on ten cups, several of which have the two primibrachs attached. The general structure of the base here, with the large portion of the basals outside the column socket, and the prominent posterior basal, has much in common with that of both *Synerocrinus* and *Talanterocrinus*, but in these genera the post. B is rather wide where it appears outside the column and is altogether more triangular in shape. It also does not appear to extend to the outer edges of radials. In the present species the post. B is comparatively narrow, and as a whole very variable in shape. With one exception among the ten specimens (Plate III, fig. 15) it always continues for a greater or less distance beyond the outer line of the radials. In all specimens it is succeeded by a single plate which from the appearance here was probably followed by a tube. This inference is strengthened by a very small specimen (No. 2057*g* not figured) which is crushed but has the rays preserved up to the second secundibrach and the indications here are that the arms are probably heterotomous. For these reasons I incline to place the species under *Talanterocrinus* rather than under *Synerocrinus*. There can be no doubt

of course that the present species comes near to *Synerocrinus incurvus* (Trautschold) and *Talanterocrinus jaekeli* Moore and Plummer in its basal features, but the variability in length and peculiar shape of the post. B in the new species are quite distinctive.

Amphicrinus scoticus Springer

Plate III, figs. 7, 10–12 ; plate IV, figs. 1, 2, 3, 5, 6, 7, 10–12.

It has already been indicated that the basal structure of *Caldenocrinus* agrees in some respects with that of *Amphicrinus* and when fragments of bases are found alone, with no evidence of the full extent of the interbrachials or nature of the arms, it is often difficult to determine to which of these genera they belong. In *A. scoticus* the basals, even in very young specimens, rarely show outside the column ; but with age, as the column socket enlarges, it seems to encroach rather more over the radials than in *Caldenocrinus* (Plate IV, figs. 5, 6). It seems probable also that resorption of the infrabasals goes much further in *Amphicrinus*. In Springer's description of *A. scoticus* (1920, pp. 337–340) it is stated that the anal interradius is occupied by a single row of plates and that in the lower region the lowest plate of the series is often missing, indicating perhaps " a case of degeneration tending toward a return to the primitive weak anal side, analogous to that of *Synerocrinus* " (Springer, 1920, p. 340). This tendency is well exemplified in the specimens shown on Plate III, figs. 7, 10, 11, and Plate IV, figs. 5, 6, 7, 10, 11. The statement, however, that the anal interradius is always occupied by a single series of plates requires some modification. Among seventeen specimens of *A. scoticus*, five have the weak anal cavity succeeded by a double range of plates (Plate III, fig. 7 ; Plate IV, figs. 6, 7, 10, 11) ; four have no weak anal cavity and begin as a single series but higher up merge to a double series (Plate IV, fig. 3). In seven specimens all plates are preserved as a single series (Plate IV, fig. 2), and in one specimen all plates, with exception of first IBr, are preserved as a double series (Plate IV, fig. 1).

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EXPLANATION OF PLATES

PLATE III

FIGS. 1, 2, 3, 5.—*Caldenocrinus curtus* gen. et sp. nov., left lateral, basal, right lateral and posterior views of holotype, No. 1088 from Seafield Tower Limestone, Seafield shore, west of Kirkcaldy, Fife.

FIG. 4.—*Caldenocrinus curtus*, basal view of paratype, No. 1633 from No. 1 Bed, Invertiel, Fife.

FIG. 6.—*Talanterocrinus jaekeli* Moore and Plummer, No. 2059 from Ardross, Fife.

FIG. 7.—*Amphicrinus scoticus* Springer, No. 708 from No. 1 Bed, Invertiel.

FIGS. 8, 9, 13, 15, 16.—*Talanterocrinus strimplei* sp. nov., Nos. 2057 *b, a, c, f, e* from No. 1 Bed, Invertiel. No. 2057*a* is the holotype.

FIGS. 10, 11. *Amphicrinus scoticus* Springer, left lateral and basal views of 2168*b* from No. 1 Bed, Invertiel.

FIG. 12.—*Amphicrinus scoticus* Springer, basal view of No. 2168*g* from No. 1 Bed, Invertiel.

FIGS. 14, 17.—*Caldenocrinus curtus*, two views of a crushed paratype, No. 1653, from No. 2 Bed, Invertiel; fig. 14 shows part of the arms and fig. 17 the crushed base with fragments of the column.

All specimens in author's collection and all figs. nat. size except fig. 6 which is × 1½.

PLATE IV

FIGS. 1, 2, 3, 5, 7, 11.—*Amphicrinus scoticus* Springer, Nos. 2058*b*, 2168*a*, 2058*c*, 2058*a*, 2168*c*, 2213, from No. 1 Bed, Invertiel. All are posterior basal views. Fig. 10 is a posterior side view of fig. 7, and fig. 12 a left lateral view of Fig. 11. In Fig. 3 the anal interradius is on the upper right side of photograph.

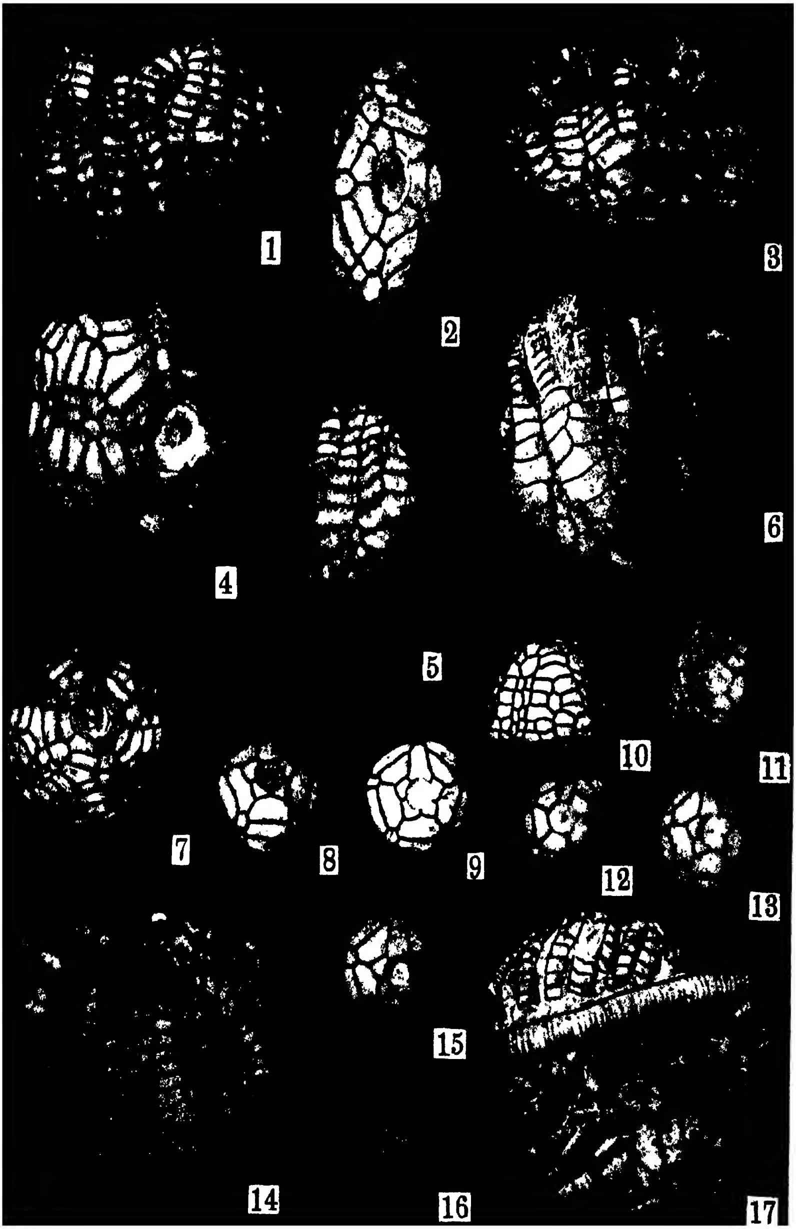
FIG. 4.—*Caldenocrinus curtus*, fragment of a base referred to this species, No. 2169*d* from No. 1 Bed, Invertiel.

FIG. 6.—*Amphicrinus scoticus* Springer, basal view of No. 2051 from Roscobie.

FIG. 8.—*Caldenocrinus curtus*, No. 2214, a paratype from No. 1 Bed, Invertiel.

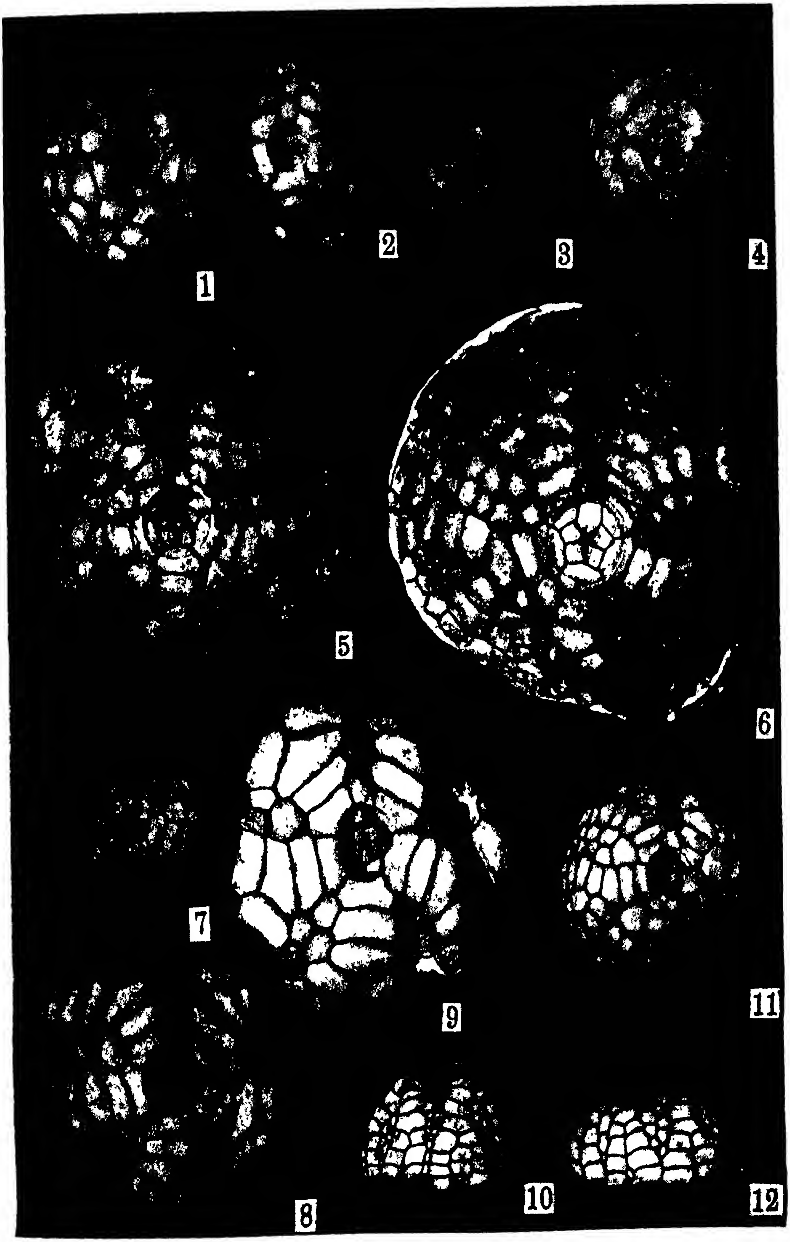
FIG. 9.—*Caldenocrinus curtus*, No. 2099, a paratype from Roscobie.

All specimens in author's collection and all figs. nat. size.



J. Wright Photo.

SCOTTISH ICHTHYOCRINIDAE



J. Wright Photo.

Scottish Ichthyocrinidae

Fossils from Middle Bunter Pebbles Collected in Birmingham

By ARCHIE LAMONT, Grant Institute of Geology, University of Edinburgh

THE most representative series of fossiliferous pebbles from the Birmingham district is that in the Evans Collection, which was acquired by the National Museum of Wales in 1937 and catalogued under the numbers 37.110 GR 1–316. For the loan of this collection I am indebted to Dr. F. J. North, and material for comparison from other collections was obtained from Dr. C. J. Stubblefield, Miss J. R. Harding, and Professor L. J. Wills, who has also corrected the typescript.

Although the immediate source of most of the pebbles was the drift of the Moseley area, South Birmingham, especially at Evans's Gravel Pit, Ladypool Lane, it has been possible to select those obviously originating from the Middle Bunter formation, and a provisional faunistic analysis is given below. Practically all the fragments dealt with are true quartzites with secondary siliceous cementation, but it is interesting to note that it is in the Ordovician examples that large flakes of white mica are frequently to be found. This proved helpful in a preliminary rough separation of many of the specimens with an Ordovician fauna from those of later date ; but in the case of specimens with *Trachyderma serrata* Salter, this method failed, as some of the quartzite slabs had large flakes of mica while others seemed to be non-micaceous. The absence of mica may indicate deposition in very shallow, wave-disturbed waters, in which mica flakes remain in suspension.

ORDOVICIAN FAUNA

LAMELLIBRANCHIA

Cadomia cf. *bergeroni* Bigot . . . 43 (57).[1]
? *Cadomia* sp. . . . 51, 173.
Cardiolaria sp. or *Pseudaxinus* sp. . . . 166A–B.
Clidophorus ? cf. *amygdalus* Salter . . . 24 (115).
Ctenodonta sp. or *Nuculana* sp. . . . 89 (90).
? *Cyrtodonta* sp. . . . 115 (24).
Lyrodesma coelata Salter . . . 22.
Lyrodesma sp. nov. . . . 41.
? *Lyrodesma* sp. . . . 154A–B.
Modiolopsis cf. *munieri* Bigot . . . 56 (230), 209A–B, 230.
Modiolopsis prima (d'Orbigny) . . . 3, 91, ? 116, 276.
Modiolopsis cf. *lingualis* Salter . . . 24 (115).
Modiolopsis sp. . . . 116.
Nucula (*Ctenodonta* ?) cf. *bertrandi* (Marie Rouault) . . . 29 (132), 43 (57).
Orthonota aff. *inornata* Phillips . . . 46, 66, 71 (76), 290A–B, 232.
Orthonota cf. *normanniana* d'Orbigny . . . 115 (24), 290A–B.
Orthonota sp. . . . 56, 100, 137.
? *Orthonota* sp. . . . 200 (14).
Pseudaxinus cf. *trigonus* Salter . . . 6A–B–C–D.
? *Redonia* cf. *deshayesiana* Marie Rouault . . . 200 (14).
? *Redonia* cf. *duvaliana* Marie Rouault . . . 18, 100.

[1] In the above lists the figures are the serial numbers of specimens in the Welsh National Museum Collection. Figures in brackets refer to counterparts of the immediately preceding unbracketed examples.

? *Redonia* sp. or *Nucula* (s.l.) aff. *beirensis* Sharpe . . . 249.
Obscure small lamellibranchs . . . 150A–B.

CEPHALOPODA

? *Endoceras* sp. . . . 299, ? 17.

PTEROPODA

Tentaculites sp. . . . 36.

BRACHIOPODA

Lingula hawkei Marie Roualt . . . 12 (122), 26, 79, 94, ? 121, 154, 191, 241.
Lingula lesueuri Marie Roualt . . . 47, 58, 82 (88), 95, 96, 133, 154A–B, ? 208A–B.
" *Orthis* " *berthoisi* var. *erratica* Davidson . . . 36.
" *Orthis* " *budleighensis* Davidson . . . 4A–B–C–D (? 61, ? 101), 20 (68), 21, 25, 27, 29 (132), 44 (293), 61 (? 101), 68 (20), 70 (138), 72, 101 (? 4), 104 (140, ? 231, 296), 117, 120, 125, 127 (130), 145, 147, 157A–B (278), 238, 239, 246, 248, 253, 256, ? 259, 265, 267, 272, 285, 292 (297), 314A–B.
" *Orthis* " *valpyana* Davidson . . . 39, 65 (303), 313A–B.

TRILOBITA

Homalonotus (*Brongniartella*) *brongniarti* Deslongchamps . . . ? 20 (68), 30, ? 35, ? 111, ? 114, ? 149A–B.

VERMES

? Worm-cast . . . 150A–B.

Specimens with *Trachyderma serrata* Salter—probably Ordovician (cf. Wyatt Edgell, 1874, p. 45)—are 2 (6B), 7, 8, 9, 34, 67 (92), 69, 219, 291.

SILURIAN FAUNA

BRACHIOPODA

Atrypa reticularis (Linnaeus) . . . 123, 136, 142, 306.
Atrypa sp. . . . 288.
? *Brachyprion* cf. *fletcheri* (Davidson) . . . 110.
Brachyprion aff. *mullochiensis* (Reed) *et anticostiensis* Shaler sp. nov. . . . 54 (301), 275.
Brachyprion sp. . . . 240.
Bilobites biloba (Linnaeus) . . . 240.
Camarotoechia decemplicata (J. de C. Sowerby) . . . 226.
Camarotoechia cf. *obtusiplicata* (Salter MS.) . . . 93, 237 (307).
Camarotoechia sp. . . . 283A–B.
? *Camarotoechia* sp. . . . 60.
Catazyga cf. *anticostiensis* (Billings) . . . 274.
Coelospira hemispherica (J. de C. Sowerby) . . . 28, 33 (251, 275), 40, 42 (245), 54, 59 (225, 294), 60, 77, 80 (254), 93 (81), 110, ? 139, 142, 199, 220, 236, 251, 275, 301, 311A–B.
Dalmanella (s.l.) sp. . . . 60, 199, 237, ? 240.
Delthyris cf. *elevata* (Dalman) . . . 142.
Leptaena rhomboidalis cf. mut. ζ Reed . . . 136, 273, 306.
Leptaena cf. *rhomboidalis* (Wilckens) . . . 93 (81).
? *Leptostrophia compressa* (J. de C. Sowerby) . . . 251.
? *Leptostrophia* sp. . . . 28.
Mendacella cf. *uberis* (Billings) . . . 236.
Orthis (? *Dolerorthis*) sp. . . . 50.
Orthis (*Dolerorthis* or *Hesperorthis*) sp. . . . 123.
Orthis (*Dolerorthis*) *psygma* Lamont and Gilbert . . . 288.
Pentamerus oblongus J. de C. Sowerby . . . 98, 139, 224.
Rhynchotreta cf. *cuneata* (Dalman) . . . 98.
? *Rhynchotreta* sp. . . . 49 (63).
Stricklandia lirata (J. de C. Sowerby) . . . 106, 142, ? 229 (264).
Stricklandia lirata forma *a* St. Joseph . . . 97.
Stricklandia sp. . . . 136.

Stropheodonta cf. *arenacea* (Salter MS.) . . . 54 (301), 109 (139).
Whitfieldella sp. . . . 93 (81), 266, 274.

TETRACORALLA

Streptelasma sp. . . . 54, 277, 301.

ECHINODERMATA

Crinoid ossicles . . . 33 (251, 275), 59 (225, 294), 60, 229 (264), 237 (307), 254, 283A–B.

GASTROPODA

Euomphalus cf. *sculptus* J. de C. Sowerby . . . 306.
Pleurotomaria (s.l.) sp. . . . 240.
? *Tentaculites* sp. . . . 60, 220.

LAMELLIBRANCHIA

Pterinaea sp. . . . 40.

CHAETOPODA

? *Cornulites* sp. . . . 77, 142.

BRYOZOA

Undetermined bryozoon colony . . . 237 (307).

DEVONIAN FAUNA

BRACHIOPODA

Athyris (*Seminula*) cf. *oblonga* (J. de C. Sowerby) . . . 257.
? *Atrypa* sp. . . . 74.
Camarotoechia cf. *elliptica* (Schnurr) . . . 85, 287, 289 (295), 298.
Camarotoechia cf. *thebaulti* (Marie Roualt) . . . 5A–B–C.
? *Camarotoechia* cf. *winwoodiana* (Davidson) . . . 211.
Camarotoechia sp. . . . 262.
? *Chonetes* sp. . . . 11A–B–C–D–E.
Dalmanella cf. *monnieri* (Marie Roualt) . . . 13, 211.
? *Mendacella* sp. . . . 128.
Spirifer cf. *hystericus* (Schlotheim) . . . 75, 78, 155A–B, 247, 270.
Spirifer cf. *verneuilii* Murchison . . . 23, 32 (83), 45, 62, 64, ? 73, 227, 255, 268, ? 269 (270), 282A–B, 286, 289 (295), 302, 308, 316A–B.
? *Spirifer* cf. *verneuilii* Murchison . . . 73.
Spirifer spp. . . . 38 (74), 148A–B.
Stropheodonta sp. . . . 73 (possibly undescribed brachial valve of *Str. vicaryi*).

TRILOBITA

Homalonotus (*Brongniartella*) sp. . . . 260.

LAMELLIBRANCHIA

Aviculopecten (*Pterinopecten*) sp. . . . 112 (244).
? *Cucullaea* sp. . . . 148A–B.
Aff. *Cuneamya* sp. . . . 305 ? Devonian.

ECHINODERMATA

Crinoid ossicles . . . 269, 298.
? Crinoid base . . . 247.

Additions to the above lists may be made from collections in the Geological Survey Museum and in the Warwick County Museum. Many other specimens are preserved in the Geological Museum at the University of Birmingham. Among the latter, one may call attention to specimens of " *Orthis* " *budleighensis* Davidson from the Middle Bunter Pebble Beds at Guest's Pit, Wollaston Ridge, where it was obtained by Dr. Frank Raw, at the Star Gravel Pit, Great Barr, where it was collected

by the Lapworth Club of Birmingham University, and at New Wood Gravel Pit, Stourton, where it was observed by Mr. W. Jeavons. These are so far the only well authenticated cases in which "*O.*" *budleighensis* has been collected from Bunter Pebble Beds *in situ*, and not possibly from drift.

A large number of Devonian plant remains have also been collected. These are mainly in the Birmingham University Geological Museum, to which some of the more important specimens have been presented by Dr. W. F. Fleet and Miss E. M. Smith. They include :—

Cyclostigma sp. and/or Stigmarian roots.
Hostimella sp.
Lepidodendron cf. *Jaschei* A. Roemer.
? *Nematophyton* sp.

The numerous points of contact between the lists recorded in this short paper and those of workers like Salter (1864), Davidson (1870, 1880, 1881), Wyatt Edgell (1874), and others for the Bunter Pebble Bed of Budleigh Salterton will at once be recognized. The fossils are essentially those of the Ordovician and Devonian anticlines and synclines of present-day Brittany and Cornwall, the Ordovician fauna of which is distinct from its contemporaries whether in England or in Ireland. The Silurian fauna, on the other hand, is clearly that of the shallow transgressive seas which covered the West Midlands of England during Upper Llandovery time (Lamont, 1940).

This work fully confirms the conclusions of C. A. Matley (1914).

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ANNOUNCEMENT

Edinburgh Geological Society

CLOUGH MEMORIAL RESEARCH FUND

This fund was instituted in 1935 for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Durham, Cumberland, Westmorland, and Yorkshire. Under the terms of administration of the fund, a sum of approximately £30 is available annually.

Applications for grants are invited for the period 1st April, 1946, to 31st March, 1947. These applications should state : (1) the nature of the research to be undertaken ; (2) the amount of grant desired ; (3) the specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in field, excavation of critical sections, etc. ; (4) whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Memorial Research Fund Committee, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st March, 1946.

REVIEWS

THE GRAVITY FIELD OF THE WESTERN AND CENTRAL MEDITERRANEAN. By H. P. COSTER. J. B. Wolters' Uitgevers-Maatschappij N.V., Groningen, 1945. pp. 1–57, with 4 folding maps.

A knowledge of the variations of the earth's gravitational field, combined with a study of geology, enables much useful information to be gained about the structure of an area. One of the best known examples of such work is the analysis made by Professor F. A. Vening-Meinesz of the conditions in the Dutch East Indies. Working on somewhat similar lines, Mr. H. P. Coster has collected together and examined the available data for the Western and Central Mediterranean region.

The gravitational field in this area has already been determined and the data used have mainly been taken from the results of the submarine gravity expeditions undertaken by the French and Italians together with a few observations made by Professor Vening-Meinesz. Altogether some 200 stations have been used, extending over an area of about 400,000 sq. miles.

As a first stage in the interpretation, it is necessary to make isostatic reductions, and this has been done for each station on the assumption that the thickness of the crust is 30 km. and that the compensation is regional. Various different "regionalities" have been used : 232·4, 116·2, and zero km. being the values actually chosen. The latter is equivalent to a Heiskanen reduction with T = 30 km. A special chart of the Western and Central Mediterranean has also been constructed on a scale of approximately 30 miles to the inch, and the gravity anomalies are clearly illustrated by means of transparent diagrams which can be superposed on the chart.

The most striking result is the large proportion of the area in which the gravity anomalies are positive (i.e. the measured value of gravity is greater than the calculated value). What negative anomalies there are tend to be concentrated in strips : a result similar to that obtained in the case of the Dutch East Indies. The conclusion is reached that in this area regional compensation with a small "regionality" (about 40 km.) gives the best result, but it is pointed out that considerable variations occur from place to place.

A detailed examination of the gravitational anomalies is then carried out, and it is suggested that a downward convection current in the substratum would account for the general positive anomalies, but that other tectonic forces may also be in operation which give rise to the comparatively local nature of the compensation.

The general geological features of the region are next considered, and an extensive bibliography given. On the whole, the geological evidence appears to agree well with the gravitational data. Dr. Coster states that there is considerable evidence that, as a whole, the region is one in which considerable subsidence has taken, or is taking, place, which agrees well with the supposition that the earth's crust yields under the influence of the excessive gravitational force. There is, however, little evidence that in any specified area there is any correlation between the gravity anomaly

and the rate of sinking, and it follows that other forces must also be in operation.

The author finally considers the seismic activity. He shows that during the period 1913–1930 about a hundred earthquakes occurred. Most of these had epicentres near Italy, while the remainder were near the south-east of Spain or in southern France. This adds weight to the argument that the earth's crust in these areas is subject to considerable forces.

In general there is a striking similarity between the conditions found in the Western and Central Mediterranean region and those in the Dutch East Indies, and the conclusion is drawn that similar tectonic forces are at work in both areas.

B. C. B.

THE PULSE OF THE EARTH. By J. H. F. UMBGROVE. pp. xvi + 179, with 94 text-figures and 6 maps. The Hague: Martinus Nijhoff, 1942. Price 7 guilders.

It is striking to find that this book, published in 1942, is founded mainly on lectures given in Holland in the years 1939–1941. That such was possible gives remarkable evidence of the indomitable spirit of the people while the occupying Germans were endeavouring to destroy the cultural and other values of the country. It is also clear that the author must have had access to some remarkably good geological libraries, including the literature up to 1941.

As is clearly implied in the title, the keynote of the book is periodicity in earth history, and this is exemplified in many ways. The first chapter contains all the usual matter as to the origin of the solar system and the earth, the age of the universe, the birth of the moon, and the dating of the geological time-table. It is interesting to note here and elsewhere how the fixing of geological ages by the lead-helium methods has quietly become an orthodoxy, without the usual chorus of protest at something new. No doubt before long someone will come along and explode an atomic bomb in the theory. In this book, for reasons which will shortly appear, a period of 250 million years plays an important part.

In Chapter II, on Mountain Chains, the usual four major periods, with about 25 minor subdivisions, are recognized, but it is maintained that of these the late Palaeozoic, which is here always called the Variscan, and the Alpine, are of greater importance than the Caledonian and the Mesozoic epochs. In the table given the four major periods are shown as continuous or overlapping, which merely goes to show that, as the present writer has often maintained, diastrophism is going on all the time somewhere in the world, which seems reasonable if we consider that the ultimate causes, whatever they may be, are probably always in operation. Special stress is laid on the fact that the time between the Variscan and Alpine periods is about 250 million years, and it is implied that there ought to have been a similar big disturbance 500 million years ago, somewhere in the Upper Precambrian, and doubtless others at earlier dates, though little is said about the Precambrian in general anywhere in the book: a rock from Manitoba with uranium at 1,750 million years is the date given as that of the oldest known. (Before that the crust may have been too soft to fold.)

Chapter III contains a very interesting and comprehensive account of basins, with a useful classification into four types: (1) marginal deep, (2) intermontane trough, (3) nuclear basin, (4) discordant basin. The first two terms explain themselves. A nuclear basin is a region between folded areas, apparently the same as Kober's Zwischengebirge, while discordant basins appear to be just casual sinkings across any kind of structure. This chapter includes some useful maps and details of the Netherlands East Indies.

Chapter IV deals with crust and substratum, sial and sima, geosynclines and isostatic anomalies, tectonic and magmatic cycles, up-doming and rifting, leading up to the origin of continents and oceans, while the fifth chapter discusses transgressions and regressions of the sea.

Chapter VI contains a detailed discussion of the floor of the oceans in the light of the latest researches, with special reference to the origin and permanence or otherwise of oceans and continents, and the possibility of formation and disappearance of land-bridges as postulated by so many biologists and geologists of like mind. The author has no use for the theory of continental drift as set out by Wegener and du Toit. One of his chief arguments against it is the supposed existence of a thin sial layer in the Atlantic and Indian Oceans. It is difficult to see much force in this argument, which seems to imply that a sialic continent could not move through sial. But icebergs can plough through pack-ice. This present writer believes that the rejection of continental drift in some form involves difficulties quite as great as its acceptance. The usual argument against it, of course, is that adequate forces are unknown. But everybody believes in the folding of mountain chains: the Alps show that it did happen, and that quite recently. But as yet we have no clear conception of what the forces were that did it. The cases surely are comparable, and it is illogical to swallow one whole and to make such a fuss about the other. Put as briefly as possible in one sentence, the author's own hypothesis is the folding and drifting, with fracture, piling up and stretching of a continuous sialic layer in early Precambrian time.

In the next chapter, on ice-ages, the rhythmic period of 250 million years is again introduced. This is the interval between what we for convenience may call the Karroo Ice Age of the late Carboniferous and the Pleistocene. It is to be specially noted that the former coincided more or less with the great Armorican-Variscan orogeny and the latter happened soon after the Alpine foldings, already emphasized as of exceptional importance, and here again, as before, this cycle is linked up with cosmic causes, including the rotation of the galaxy. These, however, are mighty matters, on which it is best not to express an opinion here.

It only remains to congratulate the author on the production under the most adverse circumstances of an extraordinarily interesting book, while mention may be made of the admirably clear figures. The excellent translation from the Dutch manuscript has been made by Mr. J. L. van Houten. The English reads very well and almost the only foreign flavour is given by a somewhat different convention in the use of capital letters in geological names.

R. H. R.

Chronology of the Pleistocene Epoch. By Richard F. Flint. *The Quarterly Journal of the Florida Academy of Sciences.* Vol. 8, pp. 1–34. 1945.

One welcomes this critical review by Professor Flint, of Yale University, of the various methods that have been employed to estimate the duration of the Pleistocene and of its subdivisions, especially in view of a tendency to lean very heavily on astronomical theories in explanation of climatic changes and to accept them as the sole basis of Pleistocene chronology. The author shows, however, that most estimates that have been made of the ages of Pleistocene events, in whatever way they have been arrived at, do show an uncanny agreement, at least in order of magnitude, with ages estimated from Milankovitch's curves of variation in the amount of solar heat received in high latitudes throughout the last million years.

After summarizing the results of a number of investigations made by geological methods Flint tells us : " The length of the whole Pleistocene epoch appears to be not less than one million years ; it is probably not more than five million years " ; but any suggestion of an approach to this high maximum estimate does not seem to be justified by the results quoted in the body of the article.

The only method that seems to offer absolute dating, when correlation of events on the lands with deep-sea sedimentation shall have been further developed, is that based on the concentration of radium in sea-floor deposits ; but " unfortunately the radium content becomes essentially constant after 300,000 to 400,000 years. Hence the method is of use only for times within this limit, and is not applicable to the whole of the Pleistocene epoch ".

The author discusses estimates of the duration of late Pleistocene time based on rates of retreat of waterfalls, retreat of wave-cut cliffs, erosion of small valleys, delta-building, accumulation of peat, sedimentation on lake floors, precipitation of travertine, radioactive disintegration of travertine, and varve-counting.

For the more difficult problem of evaluating the lengths of interglacial ages (glacial ages present a still more difficult task, but are generally thought to be relatively short) methods used have employed inferences from degree of weathering of glacially smoothed hard-rock surfaces, from depth of leaching of glacial deposits, and from loss by weathering from their surfaces. Among these various methods there is noted such an amount of agreement in the results as would encourage considerable faith in the figures obtained but for the fact that all depend equally on an assumed length of postglacial time—assumption of which is necessary to obtain a yardstick for rates of weathering, leaching, and erosional removal.

The time estimates of Sayles which have been obtained by measurement of thicknesses of residual soils in Bermuda are mentioned also. Accumulations of calcareous dune sands were formed apparently in glacial ages, when ocean level was low and strong winds blew ; but in interglacial ages soils gradually developed on these, solution of 100 feet of the material leaving one foot of soil in about 50,000 years.

C. A. C.

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The Granitization Problem

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THE invaluable Presidential Addresses by Professor H. H. Read, entitled "Meditations on Granite", Parts I and II, read to the Geologists' Association in 1943 and 1944, seem to have aroused a great deal of interest in petrological quarters, more especially as these "meditations" are painted against the lively background of the historical development of ideas embracing a whole century and a half. Professor Read's "meditations" are the more remarkable since they lead him to conclusions almost diametrically opposed to those propounded by Professor P. Niggli in an address delivered to the Zürich Geological Society at the February meeting of 1942, although both reviewers rely on about the same scope of historical "evidence".

It is of some importance that Professor Arthur Holmes has recently (1945), in a short recapitulation of the development of the subject of granitization, emphasized that it is indeed a fact that migrations of elements or oxides take place in solid matter. That such migrations take place on a *small scale* has been proved by Holmes (1936, 1945) and others (Adams 1930, Hedvall 1938), and evidence that similar processes take place on a *medium scale* has been provided by Doris L. Reynolds (1936, 1941, 1942, 1943, 1944) in a series of fundamental investigations. Yet there is still grave hesitation in applying this knowledge to the interpretation of *large* and *grand scale* phenomena, it seemingly being forgotten that all exact numerical data in petrology and geology, whether analytical or synthetical, have hitherto been acquired from small scale studies. One might question whether microscopical research can be of any use in petrology if one is to reject the possibility of extrapolation from the *small scale* (laboratory experience) through the *medium scale* into the *large* and *grand scale*. One is here reminded of the celebrated French geologist Pierre Termier, who, at the birth of the "nappe" theory some forty years ago coined the following short reply to doubts and objections raised against far-travelled nappes : "Ce n'est que le premier kilomètre qui coûte."

In the course of reading Professor Read's historical reviews, briefly discussed and somewhat amplified lately by Dr. R. H. Rastall (1945), one wonders why Clifton Ward and A. H. Green, whose field work and observations were excellent, had no immediate spiritual successors in

British petrography. And why the successors of the splendid French school of 1847—the skilful petrographers of the eighties and nineties, A. Michel-Lévy, P. Termier, Ch. Barrois, A. Lacroix, creators of the striking " tâche d'huile " and " colonnes filtrantes " analogies for describing the granitization processes—became mute, after the turn of the century, before the orchestral crescendo of discussion relating to magmatic differentiation which at that time was beginning to be claimed as the sole source of granitic (and orthogneissic) rocks. It was not until 1937 that an Algerian outlier of the famous French school (R. Perrin and M. Roubault 1937, 1939) again began to develop the classical French ideas.

What had happened in the meantime? The further progress of the conception of granitization was undoubtedly retarded, not only by the triumphal advance of the all-explaining crystal-differentiation theory (whose most ardent adherents now seem to have completely forgotten that their theory is an extrapolation from exact results acquired exclusively from *small scale* experiments) but also by a lack of outcrops in central Europe big enough and sufficiently continuous to be adapted to regional studies on the *grand scale*. Such outcrops were necessary in order to trace detailed field connections and to explore, by degrees, the various " transitional " types whose critical structures and compositions provide much of the evidence of petrogenesis. Such continuous outcrops, devoid of rock debris, soil, and vegetable coverings, and exposing smooth, unaltered rock surfaces, were only available in distant and sparsely populated countries recently uncovered from Quaternary glaciations. The sea-washed strand-flats, resulting from the secular rising of the Baltic coasts of Fennoscandia, the eastern and western coasts of Greenland, and the coast of Labrador, offer the most splendid conditions for such study, so that when the leading French geologists turned their attention to other problems, such as the development of the " nappe " theory, it is not surprising that the centre of study of granitization shifted to Fennoscandia.

In 1907 appeared the important declaration of principles by J. J. Sederholm " Om granit och gneis ", with an ample English summary " On Granite and Gneiss ", and with an extensive historical review of the development of the French ideas during the course of the preceding century. Professor Read has paid due attention to this valuable memoir, which is easily the most important contribution of its time to the evolution of French ideas and their application to the Archaean areas of Fennoscandia.

The Geological Congress of 1910 (Stockholm), especially its long (A 2, C 1) and short (B 1, B 4, B 7) excursions to various parts of the Baltic coast of Sweden, was the occasion of a crucial and temporary turning-point in the application and development of the modified French ideas. These were judged by their power to interpret the evidence displayed by the ancient Fennoscandian basement. The most representative authorities from leading countries were present at the Congress, and participated in its excursions and discussions. They included the renowned connoisseurs of the peculiar structures of the Canadian Shield, and the heads of the French school, Ch. Barrois and P. Termier. The present writer was Secretary to several sections and field excursions, and

occasionally acted as interpreter; he consequently became well acquainted with the problems and the controversies they aroused.

Sederholm demonstrated his ideas with the familiar sediments as starting point, proceeding step by step through complicated transitions to the compact granites which replace them without visible distortion. More than once he applied the expression "granitization" to the rock assemblages studied, and explained the process of their formation as a *diffuse penetration* of pre-existing (sedimentary and basaltic) rocks *by addition of extraneous material from below, without the mother rocks having undergone melting at any point* and *with partial ex-solution of surplus constituents.* In this connection he fully considered the *space problem* and brilliantly elucidated *the time sequence* of the various dynamic, chemical, and crystallization processes evidenced by the rocks. He was also careful to indicate the differences between his own standpoint and that of Holmquist: the latter admitted partial fusion and recrystallization of the mother rocks, but no diffuse additions of extraneous material.

The opposition to Sederholm's field demonstrations and interpretations was nearly unanimous, and well nigh disastrous. The petrological representatives at the Congress, influenced by the new possibility of applying "exact" physico-chemical laws and methods to petrology, just propounded in addresses to the Congress by J. H. L. Vogt (Christiania) and A. L. Day (Washington), explained the structures and interrelations of the rocks in the usual abstract way—as the complex results of magmatic action and differentiation.

Sederholm's opponents took as their starting point the even-grained, massive granitic rocks, the genesis of which was unknown but whose emplacement was supposed to have involved forcible change of place. No attention was paid to the space conditions nor to the persistent geometry of the rock structures. The very heads of the French school who were present, although they had precisely reiterated their views as to "colonnes filtrantes" in addresses read to the Congress, seem to have retired before the Fennoscandian structures and the very complicated problems they present. One member of the French school (Ch. Barrois), without wholly joining Sederholm's opponents, compromised with the statement that the problems raised were not yet ripe for solution.

Unvanquished, Sederholm continued to point out the possibility of reaching plausible solutions by comparative studies in younger formations, since he agreed with Barrois that "*gneiss and leptite are to be found of every geological age*". He stressed, in this connection, the importance of applying the Uniformitarian viewpoint to the Pre-Cambrian. As "advocatus diaboli" (his own words) he did not surrender and even at the last moment of the Congress pointed out some Alpine analogies. Nevertheless, even geologists of the local Survey, who, from their intimate knowledge of the field structures, had previously held opinions allied to those of Sederholm, now abandoned them. In contrast, a pupil of A. G. Högbom, Dr. J. M. Sobral, of Argentina, charged with the geological mapping and investigation of the Nordingrå and Ulfö areas in the coast region of Northern Sweden, in a short review addressed to the A 2 excursion members, emphatically pointed out the impossibility of explaining the relations of the local rocks by simple or complex magmatic

differentiation. He cited amongst other things the fact that Jotnian quartzite inclusions in dolerite dykes have been completely transformed to a granitic rock of rapakivi alliance, without a vestige of melting. Sobral's valuable investigations were published later (1913) as a memoir—*Contributions to the Geology of the Nordingrå Region*—which at present is difficult to obtain.

In spite of the united opposition Sederholm did not give up. The next summer (1911) he led an excursion over his own ground in Southern Finland which was attended by a flock of representative Fennoscandian petrographers, including J. H. L. Vogt. The purpose of the excursion was to clarify the new ideas on, and interpretations of, the complicated Archaean structures. This attempt also, however, ended in failure. Even if one or other of the participants agreed with Sederholm's interpretations because they had no plausible alternative explanation to suggest, yet afterwards, at home, when the kaleidoscopic diversity of visual impressions had faded, and faith in the Brögger-Rosenbusch education had been restored to its normal strength, the " dangerous " ideas were rejected. The discussions of the antagonistic majority, led by Vogt, included no reference to the three fundamental problems of the Archaean and its structures : *the space problem, the time problem, and the problem of the validity of the Uniformitarian principle as applied to the Pre-Cambrian.* This latter principle was always uppermost in Sederholm's mind.

Of course, even after this second disaster, Sederholm still pursued his own way in spite of the half-ironies with which his subsequent communications to the Nordic Geological Societies were met. He worked to establish the stratigraphy of his part of Fennoscandia, fixing easily recognizable horizons by means of the supracrustal metabasites ; he also strove to meet the demands based on chemical and physico-chemical questions. He refrained from citing the French school, and from discussing the origin of the oldest granites (and its gneisses), which he implicitly classed as magmatic descendants which had arisen from liquid melts derived from unknown depths in the interior of the earth. This partial compromise was to some extent due to the constraint effected by hasty criticism, such as that implied in the now obsolete sentence " corpora non agunt nisi soluta ", which was so frequently and wrongly cited during the 1911 excursion. Because of this constraint some of Sederholm's definitions and new names, proposed in his invaluable monographs and publications of 1923, 1926, and 1934, have an indefiniteness and somewhat changing meaning, and the annexation to the fading French school of the nineties became somewhat obscured. The obtrusive obstruction of the opposition at the 1910 Congress thus delayed the evolution of the French ideas for about sixteen years.

The problems italicized above have since been further elucidated by Sederholm's recent protagonists, Backlund and Wegmann, in a series of papers and memoirs published between 1929 and 1943. In the light of this further work Sederholm's early ideas are seen to have been on the right lines, and his compromise in deference to others to have been unnecessary ; moreover, the principles on which he based his Pre-Cambrian stratigraphical sequence have provided a firm foundation for further development.

Now Dr. Rastall, in his valuable review of Read's Addresses, raises a few questions which require answers. These questions, at first glance very straightforward, are, as a matter of fact very difficult ones that cannot be answered simply. Some of them are unfortunately still reckoned as not yet ripe for solution. The more recent work on granitization does, however, provide some hints of replies, and may be briefly summarized.

The more important questions run approximately as follows : (1) Why, in the Pre-Cambrian or the Archaean, was the volcanic activity (intrusive as well as effusive) far more intense and widespread than in later eras ? The idea underlying this question is that the Uniformitarian principle is not true, or is only partially true, for those far distant times. (2) Why is the rock resulting from replacement always granite ? (3) What is the source of the replacement materials—the " emanations ? " (4) What is the origin of the minor granitic intrusions ? Tentative answers to these questions will be found in the following outline of modern ideas on the subject.

The duration of the Pre-Cambrian (including the Archaean) era comprises three-quarters of the earth's age, which according to astronomical estimates equals about 2×10^9 years. The oldest rocks for which the absolute age is known are granites and pegmatites in Manitoba which are about $1 \cdot 8 \times 10^9$ years old. Still older than these granites, however, are the rocks into which they are intruded. These are conglomerates, including water-worn pebbles of quartzite and limestone, both containing carbonaceous matter. There are thus undeniable relics both of the existence of water and of biological conditions upon the earth before the emplacement of this old granite. It is also clear that weathering and transportation of the products of weathering were active in these far-off times, just as to-day.

The next step in this train of thought would be to extrapolate from the last quarter of the earth's history backwards to the preceding three-quarters : why should the evolution of geosynclines, each of them ending with revolution stages, be supposed to begin at the Pre-Cambrian-Cambrian boundary (about 5×10^8 years ago), the first culminating in the Caledonian orogeny, which is fully comparable materially, structurally, and dimensionally with the youngest orogeny—the Alpine ? As a matter of fact, on the basis of Sederholm's stratigraphical methods, four orogenies of different ages, and with different strikes, have now been distinguished in the Pre-Cambrian of Fennoscandia (Backlund, 1936A, 1937, 1941), and three of them have been roughly dated by absolute time measurements (Holmes, 1937).

All of them abound in granitic and gneissic rocks, but true sediments are not lacking, and become more common as the age decreases. Within the banded and massive granitic rocks, dark metabasites (metamorphosed basalts), appearing singly and in swarms, represent the surface flows and sills of the respective periods, now folded and distorted together with the containing rock. Within each orogeny all the characteristics of typical " granitization " of different grades are shown. The metabasites become boudinée, the enclosing granitic rocks become partially or completely mobilized, and finally the metabasites completely disappear. There is no thermal melting and no real assimilation (Backlund, 1943). The explana-

tion of the phenomena as the result of granitization is the only one that will satisfy the demands of geological space and time ; it is valid, not only for the Pre-Cambrian orogenies, but for those of all times. Going backwards from the Alpine orogeny to those of Pre-Cambrian times one notes, step by step, the ever increasing bulk of granitic rocks which supplant the sedimentary rocks and their included volcanics. If one subtracts all the granites and " orthogneisses " with their transitional stages, and all the acid volcanics, or substitutes all these by their original sediments, the bulk of the remaining real magmatics, i.e. the metabasites resulting from the alteration of gabbros and basalts, would be of about the same order of magnitude in the orogenies of all ages. The visual differences are mostly a function of depth, the casual sections of to-day not being strictly comparable.

There is, therefore, *no field evidence of a more intensive real vulcanicity (from abyssal depths) within the orogenies of distant Pre-Cambrian times as compared with those of the Tertiary, and there has been no gradual shifting from extreme acidity to exclusive basicity in the course of the earth's evolution through time.* And finally, *the granitization process and its intensity is independent of the age of the orogeny* in which it takes place ; *it depends only on the depth within the geosyncline.* Hence it may be concluded that the validity of the Uniformitarian principle can be extended backwards, for these fundamental processes also, into the Pre-Cambrian, as far as geological experience reaches.

Now the sediments of a geosyncline represent a large-scale assortment of the products of decay, mechanical disintegration, chemical alteration, and complete dissolution of an earlier orogeny. The cemented mechanical sediments are disintegrated afresh and undergo a more intense assortment. Chemical sediments are dissolved and redistributed, partly with a wider dispersal and partly with local concentration. The massive rocks of igneous origin (granites and basalts) undergo a complex decay. Their highly energized silicate lattices are broken down, by the leaching out of linking cations, and with considerable loss of lattice energy, and are reconstituted as sheet-lattice minerals, of the mica and clay group, with reduced lattice energies. On the other hand the minerals with condensed lattice structures, and high chemical resistance, i.e. " heavy fraction " minerals, together with a few exceptions from the " light fraction ", e.g. quartz, escape the universal process of decay. This great bulk of decay-products, carried by air and water into the all-collecting geosyncline, undergoes a highly perfect gravity sorting, and finally finds repose in sheet-like accumulations of minerals of about equal lattice energies. There is, accordingly, considerable variation in the sum of the lattice energies from one sheet to another, i.e. there is a very pronounced anisotropy in the accumulated final end-products. Towards the end of the evolution phase of the geosyncline the most soluble products of the chemical disintegration of rocks are precipitated as sheet-like bodies in the upper part of the sedimentary pile.

The living organisms within the geosyncline also perform an important function. Besides the accumulation of calcareous shells and other hard parts, both calcareous and siliceous, dispersed chemical elements are accumulated and differentially concentrated (in extreme cases rising to

10^5-fold) within the organic bodies in connection with their life functions. Amongst such elements are Fe, Mn, F, Cl, B, P, V, Cu, Ni, Co, Mo, TR, Ra, U, Th, and W, etc. Some early adherents of the classical French school indicated the significance of these exclusive accumulations, and recent work in Russia, by V. I. Vernadsky (1924, 1929, 1930) and his followers, has further emphasized the importance of such accumulations and enrichments. They are distributed within the appropriate sediments as streaks, patches, and lenses, and are found at the present day aligned roughly in accordance with the axial extension of the geosyncline.

This short review of the sedimentary filling of a geosyncline reveals that there are many gradients between the different members, dependent on density, physical (including lattice energies) and chemical differences, in spite of the fact that the materials were all on their way to the entropy level. Figuratively, they only await thermal and other activation agents to bring about an equalization.

Recognition of the problem of the replacement of the detrital clay minerals within the sediments of a geosyncline, during the revolution stage of an orogenic cycle, is at least as old as the microscopic investigation of rocks. In this connection the French school long ago coined the term " felspathization ". Now a strict comparison of chemical analyses of altered and unaltered argillaceous rocks shows that there is always a considerable addition of Na and Si, and a considerable loss of K and Al in the altered representatives. The channels of escape of the emigrants (K and Al) are invisible, as also are those which allowed the immigrants (Na and Si) to enter.

In 1917 Milch found the clay-slate wall-rocks in contact with diabase to show almost complete replacement of the K, Fe, and Mg compounds by albite and quartz, without any volume change, and without any corresponding loss of Na, Al, and Si being detectable in the adjacent igneous rock. Examples such as this, however, were for a long time regarded as special anomalies. Then Goldschmidt (1921), in the Stavanger monograph, recorded a widespread albitization of clay-slates, followed by a very conspicuous K-felspathization. The latter is manifested by the development of porphyroblasts and " augen " of microcline, which not only replace the albites in the clay-slates, but are also developed, as rounded phenocrysts, within the volcanic greenstones intercalated amongst the clay-slates. The end-products of alteration of the clay-slate are indistinguishable from the typical " orthogneisses " and granites further inland, and Goldschmidt showed them to be products of metasomatism.

The order of introduction in the Stavanger area, within the clay-slates, is first, introduction of Na and Si, followed by further introduction of Na, together with K and Si. In the greenstones Na, Ca, Fe, and Mg are introduced and K, Si, and Al driven out.

The phenomena observed in the Caledonides of Stavanger are all perfectly developed, and are now well known in the various Archaean orogenies of the Fennoscandian shield, but at the time of Goldschmidt's investigation the Fennoscandian authorities could not agree with his interpretations, and at the first field demonstration there was hardly any discussion of the space problem.

In arenaceous sediments, granitization results in the development of big phenocrysts of felspar and quartz. Again, these may result from introduction, but in some examples they probably represent migration and recrystallization within the limits of the arenaceous rock itself.

In quartzites, replacements are very conspicuous. They commonly seem to begin with the introduction of K and Al (K-felspar), followed by later introductions of Na-Al and Ca-Al, together with Fe-Mg, as indicated by the appearance of sparse biotite and magnetite. The emigration of Si is evidenced by wonderful implication structures of quartz and K-felspar. These have the appearance of eutectic structures, but the proportion of quartz to felspar varies steadily (Drescher-Kaden, 1942). It seems that the replacement of quartzites requires higher PTX conditions than are necessary for the alteration of clay-slates, because the argillaceous rocks may be completely granitized whilst an intervening quartzite layer remains completely unchanged or nearly so. The predominant fixation of K within the quartzite, in contrast with the fixation of Na in the argillaceous rocks, may indicate that the K represents material emigrating from granitized argillaceous types. Such an interpretation accords well with the lag in the granitization of the quartzites. Whether the Na-Si group of immigrants permeated the quartzites without being fixed at the particular PTX conditions prevailing when the argillaceous rocks were granitized, or whether they found easier routes and avoided entering the quartzites at all is difficult to decide. There are some indications that the former may be the correct explanation (Krokström, 1946).

The replacement phenomena shown by carbonate rocks are highly intricate, and the primary stratigraphical position and environment of each individual limestone formation is of special importance. It is this that accounts for the variability in the alteration of limestones (and dolomites) at deep-seated contacts from different localities. Where there is a sufficient afflux of Si, yet for some reason a rather slow advance of the reaction, the outer rim of the carbonate rock is substituted by a thick armour of silicate minerals, arranged zonally. Mafic constituents occur principally at the inner border and felsic constituents towards the outer border of this zone. In the felsic zone both plagioclase and K-felspar are present, and there is a steady decrease in the An content of plagioclase, combined with the appearance of quartz, as the newly born granite is approached. Most striking in this connection is the frontal advance of a zone of Fe-Mg-Si forming minerals of the diopside-hedenbergite and tremolite-actinolite groups, which are also found in a dispersed state within the limestone itself. In the latter case they form a curious sprinkled rock, commonly interpreted as the result of " dedolomitization ". In the frontal zone the cafemic minerals form a compact diopside-, or amphibole-pyroxene-rock ; as the replacing granite advances, streaks of the cafemic rock remain for a while within it, but they soon undergo a complete dissolution and disappear within the new-born granite.

In cases where there has been a rapid advance of the granitization front the pyroxene-amphibole zone is completely lacking ; it may be that it disappeared in the advancing granite as quickly as it formed. In consequence there is a direct granite-limestone contact.

In the case of the carbonate rocks the incoming elements are Si, Al, (Mg, Fe), Na, K, and Ti, whilst the outgoing material includes Ca, Mg, (eventually also Fe) and CO_2. At least 90 per cent by weight of all CaO and all CO_2 is driven out in the process of granitization.

Finally, in considering the granitization of the rocks of a geosyncline, one cannot omit the greenstones (basites), i.e. the real magmatic representatives of the contents of a geosyncline. They play a very variable, and at times a very important rôle within the sedimentary pile, their most usual home being within the clayey sediments. One hears so often of the " autometamorphism " to which the greenstones have been exposed that the term " autometamorphism " seems to have been coined on them. Yet they are mostly surface flows which may well have lost the bulk of their volatiles at the moment of eruption. Moreover, specimens of recent volcanic outflows from the great depths of the ocean bottom show no such " autometamorphism " and are not transformed to greenstones.

The greenstones, within the geosynclinal pile, represent local centres of higher energy, i.e. of high density and hardness, of strong chemical contrast with the surrounding rocks, and of high lattice energy ; there is in consequence a steep outward fall of gradients to the surrounding rocks. Such conditions tend to breed highly complex chemical and dynamical reactions, with the possibility of migrations along the gradients.

The first series of changes shown by the rocks of this group is that of amphibolitization, the metasomatic stages corresponding approximately to the various members of Eskola's " rock facies " (Eskola, 1914, 1921). As regards the migrations, amphibolitization involves a considerable loss of Ca together with an addition of Na and minor quantities of Al and perhaps of Si.

A further series of changes shown by the rocks of this group leads to the development of eclogites (Backlund, 1936 B). These changes involve loss of alkalies (chiefly Na), Al, and some Si, together with a marked increment of Ca, accompanied by the development of minerals of low molecular volume, i.e. a high packing index.

In the more advanced stages of the granitization of greenstone the resulting rocks are diorite, granodiorite, and granite ; these types depend for their development on the decisive introduction of Si, Na, and K with a corresponding emigration of the ferromagnesian constituents and Ca (Korjinski, 1937).

Elsewhere in the geosynclinal pile the typical " greenstones " may appear to be absent. They are then represented by skarn rocks with irregular outlines, variable textures, and large porphyroblasts of mafic minerals (Backlund, 1943). The conversion of the geosynclinal basaltic rocks to skarn depends on influx of Mg and loss of Ca, Fe, and K.

Why is the result of the replacement always granitic ? It is clear even from the above brief and summary statement that it is not always so. Not only does the alteration of the greenstones give rise to melanocratic rock varieties, but Fe, Mg, TiO_2, and P_2O_5, emigrant from granitized rocks, are also fixed in the frontal zone of granitized limestones and elsewhere giving rise to rocks rich in pyroxene and amphibole. Moreover, there is already some evidence (D. L. Reynolds, 1944) that the basic rocks which cap discrete post-tectonic granite masses are developed from the

invaded argillaceous rocks by introduction and fixation of cafemic materials driven from the underlying zone of granitization.

Where do the emanations come from ? A scrupulous examination of the gains and losses shown by the various representatives of the geosynclinal pile indicates that the emanations cannot be identical with Sederholm's *ichor.* Their specialization and diversity are far too great. Materials emigrant from specific geosynclinal rock types may, however, form the immigrant material fixed in some other rock variety. For example, the K driven from argillaceous rocks may be the source of the K introduced into the quartzites, and the Si driven from the quartzites may supply the Si necessary for the granitization of limestones. There is, indeed, small-scale evidence that such a process is operative (D. L. Reynolds, 1943, 1944). Yet, after considering all the possible interchanges, there still seems to be a deficiency of alkalies, especially of Na. Long ago an early adherent (cf. Termier, 1912) of the glorious French school suggested that buried rock-salt deposits might be the source of both K and Na in the " colonnes filtrantes ". The objections to such a suggestion are sufficiently obvious. Yet, even if this early French thought should merit some consideration, granitization effected exclusively within the geosynclinal rocks, by complete rearrangement of the initial elements, previously assorted during eras of evolution, merely by means of the imposition of new thermal conditions and the development of new gradients within the sedimentary pile, would become akin to some sort of " perpetuum-mobile " arrangement. Such a deduction is not in accord with broad field experience.

The significance of the term " emanation ", which is so often applied with reference to granitization, perhaps requires further explanation. In no case does it mean a circulation or advance guard of volatiles in the usual sense, as is sometimes supposed (Kropotkin, 1940). In reality it implies a migration of ions within solids by way of structural faults, deformations, and crystal discontinuities, and by means of potential differences of lattice energies, the result being a re-modelling and substitution. The micromorphological characteristics of the mineral constituents of the metamorphic rocks, and their cited appearances of " corrosion " are perfect witnesses of this.

A minor influx of Na and Si, without visible granitic affinities, but associated with suitable thermodynamic conditions, seems to be all that is necessary to start a long series of chain reactions within the geosynclinal rocks. Only in the later stages of these migrations does the association of migrating elements, including the residue of the original influx of Na and Si, together with Ti, K, Al, Fe, Ca, and Mg, released from rocks already granitized, show some resemblance to a granitic assemblage. " Pore magma " (Eskola, 1932) or " intergranular film " (Wegmann, 1935) is thus perhaps capable of existence in the later stages of the processes, and in the upper part of the orogenic zones.

The question of the minor granitic intrusions may next be reviewed. All previous investigations indicate that the metamorphism of sediments is attended by an important loss of true volatiles and their compounds. Most important of these is H_2O, but they also include CO_2, F, Cl, P, B, and others. The higher the grade of metamorphism the more complete is

the loss. Now the content of volatiles varies from sediment to sediment. For example, the content of H_2O in the claystones is at least 3 per cent by weight when these rocks are completely cemented, whereas in the quartzites it approaches nil. In the quartzites the content of Cl or F may become significant, whilst the limestones, although lowest in water content, are the most important source of CO_2 and P with advancing metamorphism. When complete granitization is effected the volatiles are vigorously expelled from the granitized rock, the final rock, the " normal " fresh granite, containing only small quantities of volatiles, especially H_2O, because most of these constituents cannot be accommodated in the lattices of the normal granitic minerals. Consequently, in front of the theatre of granitization a " cloud " of volatiles is concentrated.

There are three effects to be expected from this state of affairs. (1) The marginal parts of the granite *in statu nascendi* become enriched in occluded volatiles (including H_2O) ; the " intergranular film " becomes significant, and the granite becomes more and more like a liquid in its behaviour, although still at a relatively low temperature. (2) The tension in the rocks above the granite steadily rises and thus prepares the roof for injection by the expansion of fissures and joints. (3) The pressure within the upper part of the region of granitization becomes a hydrostatic one *pari passu* with the increasing liquidity of the granite. These border conditions create extra steep gradients of energy differences (PT), which favour a particularly rapid advance of the " granitization front ", so that small " intrusions " are formed at the higher stratigraphical levels (Kropotkin, 1940). Thus one is by no means constrained to admit that minor granitic intrusions, and dykes and veins of granitic composition, are derived from a true magma of abyssal origin, or that they are crystallized from a homogeneous igneous melt.

The foregoing review is perhaps too one-sided, and neglects much of the research done in this field in other countries outside Fennoscandia. It is written, however, with the object of filling the gap left after the French became silent at the beginning of the present century. It is also written with the intention of explaining how and why Sederholm, curiously enough actually a pupil of Brögger and Rosenbusch, undertook the further development of the subject. His grand rôle, in the face of united opposition, through decades of years, cannot be overrated. His ideas are to-day perhaps pushed further than he ever dreamed of.

The present writer owes his most cordial thanks to Dr. Doris L. Reynolds for reading the typescript, for abridgments of it conformably to the printing restrictions of to-day and for correcting the proofs.

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The Middle Grits of Derbyshire

By H. H. Swinnerton

THE River Amber on its way from the Erewash Valley Coalfield to its junction with the Derwent near Ambergate crosses the upturned edges of the Millstone Grit Series. Near the point where the river enters the grit belt at Bullbridge a boring for water was put down in the grounds of the Amber Dye Works during the latter half of the year 1936. My thanks are due to the directors of Stevensons (Dyers), Limited, for giving me every facility for examining the core, and to Mr. S. G. Clift for assisting me in the examination and in collecting. My thanks are also due to Dr. C. J. Stubblefield for valuable criticisms and suggestions during the writing up of this note.

The sequence of rocks passed through in the boring was as follows :—

	Depth in feet.	
Alluvium	16	0
Belper Grit	70	0
Shales	150	0
Shaly sandstone	170	0
Shales	200	6
Coal	202	0
Upper Kinderscout Grit	270	0

The bottom 15 feet of the top grit consisted of alternating layers of grit, curly bedded sandstone, and shale. In this and other respects it closely resembled the grit seen in the adjoining railway cutting, which was identified by the Geological Survey (3, p. 46) as the Belper Grit. The shaly sandstone at 150–170 feet may therefore be compared with a thin grit which occurs to the south of Ambergate below the Belper Grit, but normally ceases to be recognizable in the neighbourhood of Belper (3, p. 34).

Particular interest attaches to the presence of a marine band and a Carbonicola bed in the shales between the grit and the sandstone. The former, which will be referred to as the Belper Grit Marine Band, occurred at a depth of from 112–118 feet. It yielded specimens of *Lingula mytiloides* J. Sowerby at 114 feet and 118 feet, and a goniatite fauna at 112 feet and 116 feet. The collections made from the latter were examined by Dr. C. J. Stubblefield, to whom I am indebted for the following identifications and notes :—

Reticuloceras reticulatum (Phillips) mut. *superbilingue* Bisat (= mut γ). Plentiful.

Gastrioceras sp. The material was fragmentary but showed that the genus was definitely present. No specific identifications were made, though the ornamentation in some cases simulated that of *G. cumbriense* Bisat partially and indefinitely. Nothing that could be called *G. cancellatum* or *G. crenulatum* was present. No *G. lineatum* was seen and the absence of *G. ? sigma* could not certainly be stated.

Coelonautilus cf. *trapezoidalis* J. W. Jackson.

From the above information it is evident that this marine band lies near the top of the Stage R_2, named Marsdenian by Bisat (1); that is to say in the upper part of the zone of *R. superbilingue*.

In the marine band which occurs just above the Holcombe Brook coal and grit in the Rossendale anticline (8, p. 116) mut γ is found only in the base, while the rest is dominated by *G. cancellatum*. This fact excludes it from correlation with the Belper Grit Marine Band, which, though it contains *Gastrioceras*, is dominated even in its topmost layers by *R. superbilingue*. A closer correlation exists between the Belper Grit Marine Band and that which occurs below the Holcombe Brook Grit and its equivalent the Huddersfield White Rock (6, p. 249) in which also *R. superbilingue* is dominant and earlier mutations are absent.

In 1913 the Geological Survey (3, p. 39) definitely correlated the Belper Grit with the Chatsworth and Rivelin Grits of North Derbyshire and the adjoining countryside. Dr. Stubblefield informs me that subsequent work done by the Survey both in the field and on the fossils found has confirmed this correlation. Davies (2, p. 242) has shown that the Rivelin Grit lies between the zones of *G. cancellatum* and the *G. ? sigma* horizon of the mut γ zone. Dr. Stubblefield also tells me that Mr. W. N. Edwards has proved the presence of *G. ? sigma* unaccompanied by *R. reticulatum* mut γ close below the Chatsworth Grit and of *G. cumbriense* and *G. crenulatum* above it. These facts, which Mr. Edwards very kindly allows me to use, support the view that the Belper Grit lies near, if not actually at, the same horizon as the Huddersfield White Rock and the Holcombe Brook Grit

Wray (6, p. 249) has made the tentative suggestion that the Coxbench Grit is the Derbyshire equivalent of the Huddersfield White Rock and of the Holcombe Brook Grit. The evidence just summarized, however, shows that this correlation cannot be maintained. It is probable that its northern equivalent is the Longshaw Grit (4, p. 37).

The Carbonicola bed, mentioned earlier, occurs at a depth of 148–150 feet, just above the shaly sandstone. The collection made from it was examined by Professor A. E. Trueman on behalf of the Geological Survey. The following forms were reported as present :—

Carbonicola cf. *recta* Trueman.
" aff. *lenicurvata* Trueman.
" " " ? Trueman.

The occurrence of *C. lenicurvata* had been previously recorded from a level 27 feet below the Cancellatum Marine Band at Bingley (5, p. 127). In the boring here discussed it lies 110 feet below the Belper Grit and 20 feet below the marine band named after this grit. It seems, therefore, to lie within the Superbilingue Zone, and may indeed share with *Anthraconauta minima* Auctorum the credit for being the earliest non-marine lamellibranch hitherto recorded from the Millstone Grit Series (7, p. 71).

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New Species of *Taxocrinus* and *Synbathocrinus* and other Rare Crinoids from the Carboniferous Limestone of Coplow Knoll, Clitheroe

By James Wright

(PLATES VII, VIII, AND IX)

In a previous paper (Wright, 1935, p. 193) it was remarked that the crinoids of Coplow Knoll, Clitheroe, mainly consist of calices or thecae only and that specimens showing any part of the arms are extremely rare. In the paper cited, photographs were given of two specimens with arms, one being referred to a new species *Cyathocrinus patulosus* and the other to *Pachylocrinus* aff. *longidactylus* (Austin). Flexible crinoids belonging to the genus *Euryocrinus*, with part of the arm structure preserved, have also been recorded and a Poteriocrinid assigned to *Pachylocrinus conicus* (Phillips) (Wright, 1928, 1942). The latter species and *P.* aff. *longidactylus* mentioned above will probably have to be removed to another genus but it is not intended to discuss them at present. All these specimens were found at rather long intervals. I was therefore agreeably surprised on à recent visit to Coplow to find two fairly well-preserved crowns belonging to the genera *Taxocrinus* and *Synbathocrinus* and since the species represented by these specimens appear to differ from known forms they are now described in the present paper. An excellently preserved specimen of a species of *Platycrinites* was also found. . This specimen shows a good part of the arm structure and although it is not possible to determine with certainty its specific identity the type of preservation exhibited by it is so rare at Coplow that it is here deemed worthy of being placed on record. Another specimen with arms, probably belonging to the same genus and found a few years ago is also recorded (Plate VII, fig. 1 ; Plate VIII, fig. 4).

A few other more or less complete crinoids have been found at Coplow from time to time, e.g. *Mespilocrinus forbesianus* de Koninck & Le Hon with part of the column attached to the cup, a small *Cyathocrinus* with the arms spread out and nearly complete and one or two Poteriocrinids, etc., but such specimens by themselves are not complete enough for descriptive purposes. In addition to the above, some years ago my friend, Mr. Stanley Westhead, of Clitheroe, found a rather crushed crown of a *Taxocrinus* at Coplow. It was then thought to belong to *Taxocrinus nobilis* (Phillips) but cleaning and further examination now discloses its identity with the new species *T. coplowensis* described herein. I have to thank Mr. Westhead for the loan of this specimen, now regarded as a paratype of *T. coplowensis* (Plate VII, fig. 9) and for the photograph of Coplow quarry reproduced on Plate IX.

With the exception of the specimen of *Pachylocrinus conicus* (Phillips) and the second specimen of *Platycrinites* referred to above, both of which occurred in a shale-bed in the massive knoll limestone (Wright, 1928, p. 248), all the specimens mentioned were discovered on the surface of a hard grey bedded limestone, weathering yellow, one of a series which

underlie the massive reef limestone at Coplow and form part of the highly inclined beds at the base of the knoll. These beds are several feet thick, divided by partings of shale and some have very irregular or lumpy surfaces. The precise position of the crinoid layer is difficult to fix since the specimens were found on dislodged slabs and quarrying operations are at present suspended. The bedded limestones also vary somewhat in their lithology and thickness from one end of the quarry to the other. The lowest limestone forming the north boundary of the quarry, about the middle of the exposure in the direction of strike, consists of a rather dark bed. Its surface is studded with flattened calices of *Actinocrinites*, *Platycrinites* and other crinoids as well as dismembered tests of echinoids. It is overlain by a few inches of dark shale replete with flattened crinoids, etc. Among others, well preserved cups of *Synbathocrinus conicus* Phillips and flattened calices of *Brahmacrinus ponderosus* Sollas occur here and among other fossils an occasional large flattened coral, probably a *Zaphrentis*, is noticeable. Upon this limestone and shale lie the series of bedded limestones which for the most part are lighter in colour. The crinoids recorded above were found on the surface of one of these limestones probably about three feet or thereabouts from the base of the lighter-coloured series. At present these beds form the great northern slope or boundary of the quarry.

TAXOCRINUS Phillips

Taxocrinus coplowensis sp. nov.

Pl. VII, figs. 8 and 9

Crown moderately round ; arms strong with three or four bifurcations ; cup somewhat broad, rounded ; IBB within ring of BB and hidden by column ; outer angles of BB conspicuously seen outside proximal columnal ; PBrBr 3 ; SBrBr 4 or 5 ; IBrBr numerous ; IBr areas wide, first IBr elongate, hexagonal and fairly large, its lower end resting in notch between RR and followed by plates in single or double series up to or beyond SBrBr ; anal area wide with post. B extending well up between LPR and RPR ; column nodular and alternating distally, composed of thick and thinner columnals of fairly uniform thickness with crenulated edges but proximally expanding towards cup where columnals are very thin ; plates smooth or finely granular. (Note : where symbols differ in this paper from older accepted forms they are those recommended by Moore & Laudon, 1941.)

Holotype.—J. W. Coll. No. 1824, Pl. VII, fig. 8.

Paratype.—Stanley Westhead Coll. No. 175, Pl. VII, fig. 9.

Locality.—Coplow Knoll, Clitheroe.

Dimensions of Holotype.—Column 56·3 mm. (approx. $2\frac{1}{4}$ in.) ; height of crown 45·6 mm. (approx. $1\frac{3}{4}$ in.) ; width of crown 46·4 mm. (approx. $1\frac{7}{8}$ in.) ; average diameter of column distally 6 mm. ; average diameter of proximal columnals next cup 9·6 mm. ; distance below cup where expansion of column begins 10 mm.

Remarks.—Although the present species has some points in common with certain American forms (e.g. *T. colletti* White) its nearest relative

appears to be the English species *T. nobilis* (Phillips). The specimen originally figured by Phillips (1836, pl. iii, fig. 40) has been very fully discussed and refigured by Springer (1920, pp. 394–5, pl. liv, figs. 1*a–c*) and is stated to come from Bolland. It is in the British Museum (Gilbertson Coll.) but the exact locality is not known. In the two specimens now assigned to *T. coplowensis*, the arm structure so far as preserved does not appear to differ much from that of *T. nobilis* and on this ground alone there would seem to be no reason for creating a new species. Cleaning both holotype and paratype, however, has disclosed the wide nature of the interbrachial areas in *T. coplowensis* and the fact that these areas are occupied by a series of comparatively large plates. This is in sharp contrast to the interbrachial areas in *T. nobilis* which, as pointed out by Springer, are narrow and occupied by relatively small and few plates. This constitutes the chief difference in *T. coplowensis*. The anal interradius in our new species, as shown by the paratype, also appears to be wider.

As may be noted from Plate VII, fig. 8, the holotype shows a good part of the column with the characteristic widening shown by many species of *Taxocrinus* towards the cup. This proximal part of the column is not so well seen in the photograph as one could wish, since a dark patch here, originally covered by matrix, obscures the fine details of the thin columnals. The cup plates are slightly displaced but are otherwise well preserved. The basals are prominently displayed beyond the proximal columnal. The crown shows two of the interbrachial areas fairly complete but the plates are much disturbed in the area on right. It is not possible to state the orientation of the crown since the anal interradius is hidden in the matrix. In the right interbrachial area, however, the first plate, hexagonal in shape, and large as compared with the same plate in *T. nobilis*, is well seen. In the left interbrachial area the plates are little disturbed although somewhat sunk below the level of the adjoining rays. The lowest plate corresponds in shape and size with that of the right area. It is followed by two plates, a large and a small one, which cross the area from side to side. They are surmounted by three plates also crossing the area, then two, and finally three single plates in upward succession. In the holotype there are indications of interbrachials between the secundibrachs but they are much displaced. Unfortunately the arms above the secundibrachs are considerably disturbed and obscure the branching of the rays. On the right of the crown, however, part of a ray showing what are probably the tertibrachs can be seen curving inwards.

The paratype is squeezed downward on the surface of the limestone slab (Plate VII, fig. 9). From it, however, we can obtain a better idea of the shape of the cup. The anal area is at the top centre of photograph. Part of the proximal end of the column is still adherent to the cup and a broken portion lies directly under the attached part. The basals are well seen projecting beyond the column. The lower parts of two interbrachial areas, in the left postero-lateral and left anterior interradii can be seen on the left centre of photograph and the large hexagonal plates filling the bottom of these areas and their resemblance to the corresponding plates in the holotype may be noticed. Like the holotype, none of the rays in the paratype are complete although the right posterior, right anterior, and anterior rays show remains of higher portions than the holotype.

The general appearance of both specimens suggests that in the character of the arms *T. coplowensis* does not differ much from *T. nobilis*. The column is not known in the latter species.

SYNBATHOCRINUS Phillips

Synbathocrinus anglicus sp. nov.

Pl. VII, fig. 10; Pl. VIII, fig. 1

A species with rapidly tapering cup and low, somewhat pointed, basal circlet; RR over three times higher than BB; arms long, broad, and heavy; BrBr short with parallel sutures, fairly uniform in height except $PBrBr_1$ which are over three times higher; anal interradius occupied by two plates, the lower one angular at bottom resting in a slight notch between LPR and RPR, rather long with parallel sides and followed by the upper plate which is somewhat triangular in shape and less than one-third as long; plates smooth.

Holotype.—J. W. Coll. No. 1825, Pl. VII, fig. 10; Pl. VIII, fig. 1.

Locality.—Coplow Knoll, Clitheroe.

Dimensions of Holotype.—Length of specimen over all 64·7 mm. (approx. 2½ in.); height of cup 10 mm.; height of RR 7·6 mm.; height of B circlet 2·4 mm.; width of cup LPR to RAR 16·3 mm., post. to ant. 14·8 mm.; width of RR at top LAR, AR and RAR 9 mm., LPR and RPR 10 mm.; height of $PBrBr_1$ 6 mm; average height of BrBr above $PBrBr_1$ 1·9 mm.; width of $PBrBr_1$ at top, left post. 7·9 mm., right post. 7 mm., right ant. 6·6 mm., ant. 7 mm., left ant. 7·5 mm.

Remarks.—The holotype of the present species is excellently preserved. When found the crown was embedded in the limestone the cup only being partly exposed and care had to be exercised in developing the arms from the matrix. The distal portions of the arms were not found. Specimens of various species of *Synbathocrinus*, some of them showing the full extent of the arms, have been found in the United States. In England the only species hitherto known is *S. conicus* Phillips (1836, p. 206, pl. iv, figs. 12, 13). Both genus and species were founded on one cup which is stated to come from Bolland. Cups of the type figured by Phillips are occasionally found at Coplow, especially in the dark shale already mentioned at the foot of the knoll and for comparison with the new species six of these cups are figured on Plate VII, figs. 2–7. In the characters of the cup there is no doubt that our new species differs considerably from Phillips's species. In *S. anglicus*, the low basal circlet and the rounded nature of the radial circlet at once attract the eye. As a contrast, in *S. conicus*, the basal circlet is relatively high and prominent, often swelling out beyond the line of the radials and in some specimens forming a button-like attachment below the radials. The sutures between basals are rarely discernible. The radials are also relatively shorter than in *S. anglicus*. At first consideration was given to the idea that the new specimen might be a variety of *S. conicus* and before deciding this matter nineteen cups from Coplow were examined and measured. Six typical examples are here tabulated.

S. conicus	Height of cup	Height of RR	Height of BB
1830*a*	11·7 mm.	7 mm.	4·7 mm.
1830*b*	10 mm.	6 mm.	4 mm.
1830*c*	11 mm.	7·3 mm.	3·7 mm.
1830*d*	11 mm.	6 mm.	5 mm.
1830*e*	9·5 mm.	6·5 mm.	3 mm.
1830*f*	9 mm.	6·5 mm.	3 mm.
S. anglicus	10 mm.	7·6 mm.	2·4 mm.

Although from this examination it can be demonstrated that the cups of *S. conicus* are somewhat variable in outline the general habitus is quite distinctive. When viewed from the side the radials are in many cases concave, expanding to the top of cup with the sutural areas between radials standing out prominently. Some cups are less pronounced in this respect but none show the comparatively smooth rounded outline or low basal circlet of *S. anglicus*. The cup of the latter species has therefore a different aspect. When comparing the cups of *S. conicus* (Pl. VII, figs. 2–7) with that of *S. anglicus* it has to be noted that the proximal columnal is still adherent to the cup of our new species as shown on Plate VII, fig. 10, and Plate VIII, fig. 1. As regards the arms, these elements in *S. conicus* seem only to be known from one specimen figured by the Austins (1843–7, pl. xi, fig. 5*b*). This specimen is stated to come from Barry Island, Bristol Channel, and according to the figure, which is propably a posterior view, is much smaller than the holotype of *S. anglicus*. The figure itself is not too clear but one gathers that the brachials are relatively higher than in our new species. The cup is not well delineated in the figure but the detached cup shown on figs. 5*c*, *d*, *e*, on the same plate does not seem to differ greatly from typical cups of *S. conicus*. Another specimen with arms, considered by the Austins as *S. conicus* is shown on their plate xi, fig. 5*a*. It is stated to come from Hook Head, S. Ireland, but does not, so far as can be judged, represent a *Synbathocrinus* at all since the primibrachs are axillary and support two arms to the ray. The cup here is flattened and the appearance suggests that it belongs to a dicyclic crinoid of some other genus. Regarding the length of the arms in *S. anglicus*, in the holotype they are only preserved to probably about half their full extent. This is indicated by the very slight taper of the preserved arms and by comparison with the figures of such a complete individual as that of *S. dentatus* Owen and Shumard, from the Mississippian of the U.S. (Springer, 1923, pl. 5, fig. 9, Moore & Laudon, 1943, pl. 1, fig. 9). In *S. anglicus*, however, the arms appear to be relatively broader with shorter brachials and in *S. dentatus* the cup has more resemblance to *S. conicus* than to *S. anglicus*. Traces of the anal tube in our new species can be detected at the top of specimen between left and right posterior rays and an end section of this structure at the extremity of the arms where they are broken away.

Platycrinites Miller

Two specimens with arms from Coplow

On Plate VII, fig. 1, is shown the specimen of *Platycrinites* with arms recently found at Coplow and on Plate VIII, fig. 4, another specimen belonging probably to the same genus and found some years ago. Unfortunately,

the species to which these specimens belong cannot be determined with certainty. Possibly both belong to undescribed species but the evidence in this respect is at present too scanty. The specimen on Plate VII, fig. 1, has the cup fairly well preserved although the basal circlet is considerably squeezed. The radials are intact all round the cup but the arms are only preserved on one side of the specimen, as shown in the photograph. Although carefully searched for, no trace of the tegmen could be found. As indicated by the preserved portions, the number of arms to each ray is four which, if constant all round the crown, gives a total of twenty arms for this crinoid. In this respect the species would seem to resemble *P. laevis* Miller but judging from Hook Head (Ireland) specimens of this species and from figures by Miller (1821), the Austins (1843–7), and de Koninck & Le Hon (1854) the Coplow species is much larger. First thoughts were that our specimen might belong to *P. gigas* Phillips but although somewhat worn the cup plates of the Coplow specimen show traces of a tubercular ornamentation. This latter evidence appears to exclude the species from *P. laevis* or *P. gigas* and links it more to *P. bollandensis* Wright (1938, p. 281, pl. xi, figs. 11, 13) the cup of which is similar in shape and has a tubercular ornament. In the meantime I incline to place the specimen under this species with some reservations.

The other specimen on Plate VIII, fig. 4, is exceedingly interesting. It shows one complete ray only and the branching here gives a total of thirteen arms. Assuming the same number for the other rays this crinoid would have a total of sixty-five arms and in life must have been a magnificent creature on the sea-floor. As to the species, there is a probability that it belongs to *P. gigas* Phillips. Large thecae of this species are not uncommon at Coplow. When the specimen was disinterred from the shale-bed in the knoll limestone the cup shattered and broke in fragments. Before this happened, however, it was noticed that it resembled other detached cups of large size found at Coplow and these are not distinguishable from *P. gigas*. A medium-sized theca of this species is shown on Plate VIII, figs. 5–7, and two younger specimens of the same species on the same plate, figs. 2 and 3. Reference has already been made to this species, which occurs in all stages of growth at Coplow (Wright, 1938, pp. 272–4, pl. ix, figs. 2, 5, 8). The more mature examples rarely show the anal tube in position but younger individuals occasionally have the structure intact. The small flattened specimen shown on Plate VIII, fig. 2, is typical but rounder, and more solid examples are sometimes found. The cup of our specimen with the arms resembled that of the medium-sized example shown on Plate VIII, figs. 5–7, but was considerably larger. Altogether, on the evidence available, it seems not unlikely that these arms belong to *P. gigas*. Should this surmise turn out to be correct the name of the species would receive further emphasis.

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EXPLANATION OF PLATES

All specimens from Coplow, Clitheroe, and in author's collection unless otherwise stated

PLATE VII

All figs. nat. size

FIG 1.—Specimen provisionally referred to *Platycrinites bollandensis* Wright, No. 1826.

FIGS. 2–7.—*Synbathocrinus conicus* Phillips, 6 cups showing side, top, and basal views, Nos. 1830 a–f.

FIG. 8.—*Taxocrinus coplowensis* sp. nov., No. 1824, the holotype.

FIG. 9.—*Taxocrinus coplowensis* sp. nov., No. 175, Stanley Westhead Coll., the paratype.

FIG. 10.—*Synbathocrinus anglicus* sp. nov., No. 1825, anterior view of holotype.

PLATE VIII

All figs. nat. size except fig. 1 which is × 1½.

FIG. 1.—*Synbathocrinus anglicus* sp. nov., No. 1825, posterior view of holotype.

FIGS. 2, 3, 5–7.—*Platycrinites gigas* Phillips ; fig. 2, a small flattened specimen showing anal tube in position ; fig. 3, a small rounded specimen from posterior, tube broken off; figs. 5–7, a moderate sized theca without anal tube, posterior, right lateral, and anterior views.

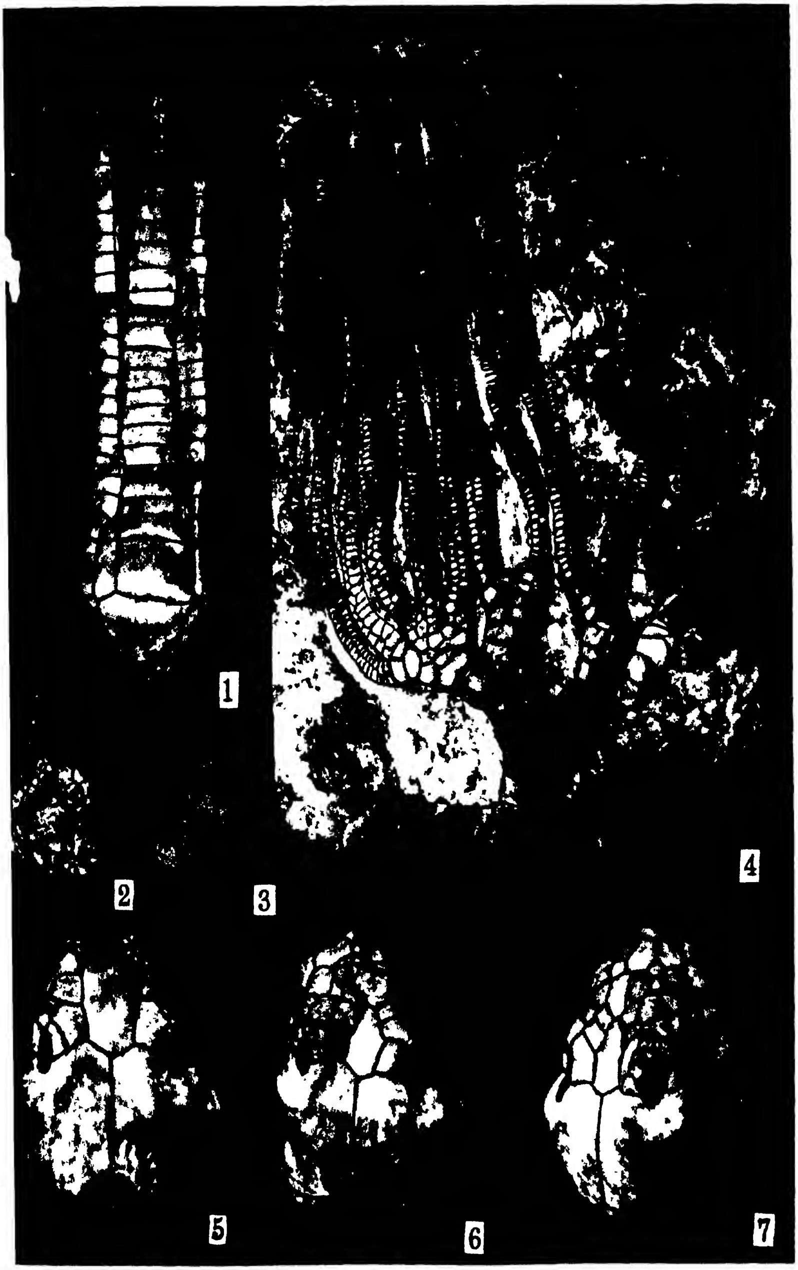
FIG. 4.—One of the rays of probably *Platycrinites gigas* Phillips, showing thirteen arms in all.

PLATE IX

View of Coplow Quarry, Clitheroe, showing north face in 1938. On the extreme left of photograph is seen the lowest dark limestone and shale referre to in text. The overlying bedded limestones form a kind of buttress on the middle left of photograph. The whole of the foregroun i.e. the floor of the quarry, up to and beyond the figure of a man consi of the massive knoll limestone. Just beyond the figure is a diagon white line which indicates where quarrying operations were bein conducted at a considerably lower level. A great quantity of th massive limestone has now been removed and at present (1945) t whole of the quarry floor is much deeper than that shown in the phot graph. Some of the upper layers of the bedded limestones have al been removed down to the lower level of the quarry with the res that the present north boundary forms a high and steep wall. T extension of the massive reef limestone which forms the boundary the quarry on the east is seen on middle right of photograph. Beyon the confines of the quarry in the distance is part of the profile of Pendl. Hill.

J. Wright Photo.

CRINOIDS FROM COPLOW KNOLL, CLITHEROE.



CRINOIDS FROM COPLOW KNOLL, CLITHEROE.

Stanley Westhead Photo.

COPLOW QUARRY, CLITHEROE, 1938

A Revision of the Upper Oxfordian Ammonites of Trept (Isère), Figured by de Riaz

By W. J. Arkell

IN his monograph published in 1898, " Description des Ammonites des Couches à Peltoceras transversarium (Oxfordien Supérieur) de Trept (Isère)," A. de Riaz figured just under 100 ammonites, in 19 folio plates, of which 15 were devoted to the genus *Perisphinctes*. This work made known to geologists one of the most important Upper Oxfordian ammonite localities in the world, of special interest from its position in the Rhone valley, on the borderland between the Jura and the North-West European and Tethyan provinces. But in spite of the excellence of de Riaz's photographs, their value is much reduced by the lack, in most cases, of either ventral views or whorl-sections, and by the failure to show septal sutures. Further, many of the photographs are more or less reduced, although stated to be of the natural size. The difficulty of identifying species from de Riaz's work, therefore, is great ; especially since for identification of members of the genus *Perisphinctes* a series of specimens at different growth-stages is usually indispensable.

A critique and ostensible revision of de Riaz's work, immediately after its appearance, was added by Siemiradzki as an appendix to his monograph on the Perisphinctidae (1899). A list of the Trept ammonites, incorporating Siemiradzki's changes, has been published by Roman (1926). Advances in palaeontology in the last forty years, however, have shown that Siemiradzki's rectifications of de Riaz's work were too hasty, and that his own determinations and classification stand in serious need of revision.

In 1936, through the kindness of Prof. F. Roman, I had the opportunity of examining the de Riaz collection at the University of Lyon, of making measurements and notes on the types, and comparing them with photographs of English ammonites brought with me. I also obtained from a villager at Trept a collection of ammonites gathered on the arable fields at the type locality (where the quarries have long fallen into disuse) and these have been valuable in making comparisons at home. Subsequently Professor Roman kindly sent me casts of the Trept Cardioceratids figured by de Riaz.

The importance of the Trept fauna, and its availability to students through de Riaz's work, sufficiently explain the publication of this revision. The type specimens were reported in 1945 to be safe at Lyon.

This paper was accepted in 1939 for publication in the *Travaux du Laboratoire de Géologie de l'Université de Lyon*, and was translated into French by Prof. Roman, but first the war and then the death of Prof. Roman in 1943 supervened, and it now appears that for financial and other reasons there is no prospect in sight of resuming publication of the *Travaux*.

Annotated List of Revised Determinations, following de Riaz's Plates and Figures

PLATE I

Perisphinctes (*Arisphinctes*) *plicatilis* (J. Sowerby). Wholly septate. Venter nearly smooth towards the end. This is the true *plicatilis*, but the ribs are somewhat sharper than usual. (Arkell, 1939, p. 145, pl. xxix.) *P. bocconii* Gemm., with which Siemiradzki identified it, is unrelated.

PLATE II

Perisphinctes (*Perisphinctes*) sp. nov. aff. *martelli* (Oppel). Siemiradzki (1899, p. 344) wrongly identified this with *P. biplex* (Sowerby). Boden (1911, p. 45) called it a typical *martelli* ; but it is clearly not conspecific with the holotype of *P. martelli*, figured by Douvillé (1904, no. 51). It may be the adult of some of the indeterminable inner whorls figured by de Riaz on other plates.

PLATE III

Fig. 1*a*, *b*. *Perisphinctes* (*Dichotomosphinctes*) sp. Diameter 105 mm. (not 98 mm.). Wholly septate ?

Fig. 2. *P.* (*Dichotomosphinctes*) sp. indet. Indeterminate nucleus. Wholly septate.

Fig. 3. *P.* (*Dichotomosphinctes* ?) sp. Wholly septate. Diameter 108 mm. (not 100 mm.). Thicker whorl than fig. 1. Possibly nucleus of *Perisphinctes sensu stricto*. Wrongly identified as *P. wartae* Bukowski by Ronchadzé (1917, p. 20).

Fig. 4. *P.* (*Dichotomosphinctes* ?) sp. Septa show clearly to 120 mm. diameter, but there are also uncertain traces of septation at the aperture.

PLATE IV

Fig. 1. *P.* (*Dichotomosphinctes*) *tizianiformis* Choffat. According to Klebelsberg (1912, p. 169) this is typical.

Fig. 2. Indet.

Figs. 3, 4*a*, *b*. Indet. Nuclei.

Fig. 5. *P.* (*Perisphinctes*) *kiliani* de Riaz. Lectotype. Wholly septate nucleus. Perhaps the same as *P. chloroolithicus* (Gümbel). (See Arkell, 1938, p. 101, for discussion.)

Fig. 6. *P.* (*Kranaosphinctes* ?) sp. indet. Nucleus. Possibly same as Plate VI.

PLATE V

Perisphinctes subgenus et species indet. Traces of septa on venter near aperture. Siemiradzki (1899, p. 343) identified this as *P. orientalis* Siemiradzki ; Spath (1931, p. 416) queried the identification.

PLATE VI

Perisphinctes (*Arisphinctes*) sp. indet. Wholly septate. The venter is very badly preserved except in the last quarter whorl, where it is moderately flattened and crossed by biplicate and a few triplicate ribs.

PLATE VII

Fig. 1. *Perisphinctes* (*Arisphinctes*) *treptensis* Simionescu (1907, p. 138). Holotype. Wholly septate. Diameter 95 mm.

Figs. 2, 3*a*, *b*. *P.* (*Discosphinctes*) *lucingae* (Favre). Both wholly septate. Contrasted with fig. 4 these are more involute, have a higher and more compressed whorl, a much more sharply ribbed venter, no constrictions, shorter N-lobe and smaller auxiliary lobes.

Fig. 4. *P.* (*Arisphinctes*) cf. *kreutzi* Siemiradzki. A wholly septate nucleus with very long N-lobe and elaborate, large auxiliaries, close to *P. plicatilis* (J. Sowerby). Siemiradzki (1899, p. 344) wrongly identified this with his *P. jelskii*, but Ronchadzé (1917, p. 29) is more nearly correct in calling it a variety of *P. kreutzi*, if that is an *Arisphinctes*.

Figs. 5*a*, *b*. *P.* (*Dichotomosphinctes*) *pseudocrotalinus* Kilian and Guébhard (1903, p. 780). Holotype. Wholly septate. Belongs to Buckman's *Otosphinctes* group (See Arkell, 1938, pp. 90–94).

Fig. 6. Ditto, with quarter whorl of body-chamber. Diameter 80 mm. (not 73 mm.). Septate to 70 mm.

PLATE VIII

Fig. 1. *P.* (*Arisphinctes*) *helenae* de Riaz. Lectotype. Wholly septate. Fully discussed, Arkell, 1939, pp. 149–154.

Figs. 2, 3. *Perisphinctes* indet. Fig. 2 deformed.

Fig. 4. *Perisphinctes* sp.

Figs. 5*a*, *b*. *P.* (*Dichotomosphinctes*) *buckmani* Arkell ? Whorls are flat-sided and rather high, the ribs sharp. Same as Plate XII, fig. 1? See Arkell, 1938, p. 82.

PLATE IX

Fig. 1. *P.* (*Arisphinctes*) sp. Wholly septate. Ribs near aperture becoming feeble on venter and mainly triplicate.

Fig. 2. *P.* (*Arisphinctes*) sp. Nucleus (wholly septate) with long N-lobe and large auxiliaries. Close to *P. plicatilis* but more evolute.

Figs. 3, 4, 5*a*, *b*. *Perisphinctes* subgenus et sp. indet. Small nuclei. Ronchadzé (1917, p. 40) identified them with *P. jelskii* Siemiradzki.

PLATE X

Figs. 1*a*, *b*, 2. *Perisphinctes depereti* de Riaz. Syntypes.

Figs. 3*a*, *b*, 4. *P.* (*Discosphinctes* ?) sp. Siemiradzki (1899) identified these with his *P. aeneas* var. *plana*. See also Klebelsberg (1912, p. 210). At least fig. 3 is probably *P. idelettae* de Riaz (Plate XV, fig. 2).

Fig. 5*a*, *b*. *P.* (*Dichotomosphinctes*) *luciae* de Riaz. Holotype. Diameter 100 mm. (not 92 mm.). Septa visible to about 65 mm. Probably $\frac{3}{4}$ whorl of body-chamber. Siemiradzki (1899, p. 342) and Klebelsberg (1912, p. 204) wrongly merged this in *P. dybowskii* Siemiradzki ; Spath (1931, pp. 439–10) rightly disagreed.

Figs. 6*a*, *b*, 7. *P.* (*Kranaosphinctes*) sp. (*sayni* de Riaz ?). Simionescu (1907, p. 128) identified these nuclei with his *P. romanicus*, but the whorl-shape is different. They may be nuclei of *P.* (*K.*) *sayni* de Riaz, Plate XV, fig. 5.

Fig. 8. *Perisphinctes* sp. indet.

PLATE XI

Fig. 1. *P.* (*Dichotomosphinctes*) *wartae* Bukowski.

Fig. 2. *P.* (*Discosphinctes*) cf. *castroi* Choffat (= *P. lusitanicus* Siemiradzki). Wholly septate. Diameter 77 mm.

Fig. 3. *P.* (*Arisphinctes* ?) *choffati* de Riaz. Holotype. Wholly septate.

Fig. 4. *P.* sp. indet. An indeterminate nucleus, deformed and distorted.

Fig. 5. *P.* sp. indet. Small nucleus, probably nothing to do with fig. 3, which has no characters visible until a much larger diameter.

PLATE XII

Fig. 1. *P.* (*Dichotomosphinctes*) *buckmani* Arkell ? Wholly septate nucleus. See Arkell, 1938, p. 79.

Figs. 2*a*, *b*, 3. *P.* (*Dichotomosphinctes*) *antecedens* Salfeld ? See Arkell, 1938, p. 83. Fig. 3 a nucleus.

Figs. 4*a*, *b*, 5. *P.* (*Dichotomosphinctes*) *elizabethae* de Riaz. Fig. 4, lectotype ; $\frac{5}{8}$ whorl of body-chamber ; septate to 68 mm. ; whorl-thickness reduced by crushing. Siemiradzki (1899, p. 344) wrongly united this species with *P. gerontoides* Siemiradzki, a *Discosphinctes.*

Figs. 6*a*, *b*. Not a Trept specimen.

PLATE XIII

Perisphinctes (*Perisphinctes*) *chloroolithicus* (Gümbel) ? Sutures nowhere clearly seen. See Arkell, 1938, p. 96. So identified also by Siemiradzki, 1899, p. 343. All or most of the body-chamber is missing, broken off at the point where the ribs have just begun to modify to form a variocostate.

PLATE XIV

Perisphinctes (*Perisphinctes*) *de Riazi* Siemiradzki (1899, p. 309). Holotype. Wholly septate. This is also a variocostate, broken off where the ribs have just begun to modify. On the last quarter whorl the ribs are quadruplicate with prominent points of furcation and the venter is flat. The penultimate half-whorl is crushed and there results a deceptive rounding of the venter. Misidentified by Spath (1934, p. 7) as a *Biplices.* It is a *Perisphinctes sensu stricto*, perhaps identical with *P. parandieri* de Loriol (1903, p. 90, pl. vii, lectotype designated by S. S. Buckman). (See Arkell, 1939, p. 109.)

PLATE XV

Fig. 1. *P.* (*Dichotomosphinctes*) sp. aff. *elizabethae* de Riaz (cf. Plate XII, fig. 4). Siemiradzki (1899, p. 343) rightly denied the identity of this with his *P. cracoviensis* (1891, pl. iii, figs. 1, 4), a *Discosphinctes*, but wrongly equated it with *P. leiocymon* Waagen, an *Ataxioceras sensu lato.*

Fig. 2. *P.* (*Discosphinctes*) *idelettae* de Riaz. Holotype. Note parabolic ribs.

Fig. 3. *P.* (*Discosphinctes*) *richei* de Riaz. Holotype. Diameter 88 mm. The last $\frac{1}{4}$ whorl appears to be body-chamber. Siemiradzki (1899, p. 344) identified this as *P. castroi* Choffat (1893, pl. x, fig. 5, lectotype designated by Spath) (= *P. lusitanicus* Siemiradzki), but it is more evolute and its

ribbing is not identical. *P. richei* differs from the closely allied *Discosphinctes* in de Riaz's Plate XI, fig. 2, by being more evolute with more slowly enlarging whorl.

Fig. 4. *Perisphinctes* subgenus et sp. indet. Nucleus.

Fig. 5. *P.* (*Kranaosphinctes*) *sayni* de Riaz. Holotype. Wholly septate, but no sutures well seen. Whorl-section circular. Venter still strongly ribbed at aperture. Plate X, figs. 6, 7, may represent nuclei of *P. sayni.* (See Arkell, 1939, p. 177.)

PLATE XVI

Fig. 1. *Perisphinctes* (*Kranaosphinctes* ?) cf. *navillei* Favre. See Arkell, 1939, pp. 186, 187. This is not related generically to the Lower Kimeridgian *Am. doublieri* d'Orbigny (see Types du Prodrome, vol. ii, p. 42, pl. xliv, figs. 20, 21).

Figs. 2*a*, *b*, 3. Incertae sedis. (Specimens not seen.) See Gérard, 1936, p. 214.

Fig. 4. *Lytoceras* cf. *polyanchomenum* Gemmellaro.

Fig. 5. *Lissoceras* cf. *erato* (d'Orbigny).

Fig. 6. *Cardioceras* sp. indet. Nucleus.

Fig. 7. *Cardioceras* (*Cawtoniceras* or *Maltoniceras*) sp. indet. Nucleus.

Fig. 8. *Cardioceras* (*Subvertebriceras*) sp. nov., aff. *densiplicatum* Boden.

Figs. 9, 10. *Phylloceras mediterraneum* Neumayr. (Loczy regards this as a synonym of *Ph. zignodianum* d'Orbigny.)

Fig. 11. *Sowerbyceras tortisulcatum* (d'Orbigny).

Figs. 12*a*, *b*. *Ochetoceras* (*Campylites*) *henrici* (d'Orbigny).

Figs. 13, 14. *Ochetoceras* (*Trimarginites*) aff. *arolicum* (Oppel).

Figs. 15, 16. *Taramelliceras* ? (*Proscaphites* ?) spp. (not seen).

PLATE XVII

Figs. 1*a*, *b*. *Ochetoceras* (*Campylites*) *henrici* (d'Orbigny).

Figs. 2*a*, *b*, 3*a*, *b*. *Ochetoceras* (*Ochetoceras*) *canaliculatum* (von Buch), var. *hispidum* (Oppel).

Figs. 4, 5, 6. *Ochetoceras* (*Ochetoceras*) *canaliculatum* (von Buch).

Figs. 7, 8. *Taramelliceras bachianum* (Oppel).

Figs. 9, 10. *Taramelliceras* cf. *gmelini* (Oppel).

PLATE XVIII

Figs. 1–5. *Taramelliceras* spp. (See below).

PLATE XIX

Figs. 1*a*, *b*, 2. *Peltoceras* (*Gregoryceras*) *romani* de Grossouvre (1917, p. 64). Fig. 1 lectotype.

Figs. 3, 4. *Peltoceras* (*Gregoryceras*) *transversarium* (Quenstedt) (*teste* de Grossouvre 1917, p. 61).

Figs. 5*a*, *b*, 6. *Aspidoceras* (*Euaspidoceras*) *tietzei* Neumayr, nucleus (*teste* Dorn, 1931, p. 19).

Figs. 7, 8, 9*a*, *b*. *Aspidoceras* (*Euaspidoceras*) *oegir* (Oppel). Collot (1917, p. 8) made de Riaz's fig. 8 holotype of a new species, *A. riazi*

Collot ; but Dorn (1931, pp. 17, 19) seems to be right in regarding it as a synonym of *A. oegir* (Oppel).

Fig. 10. *Aspidoceras* (*Euaspidoceras*) *favrei* de Riaz. Holotype.

Faunal List

Genus PERISPHINCTES Waagen

Subgenus Discosphinctes Dacqué

P. idelettae de Riaz. Pl. xv, 2 ; ? pl. x, 3.
P. richei de Riaz. Pl. xv, 3.
P. cf. *castroi* Choffat. Pl. xi, 2.
P. lucingae (Favre). Pl. vii, 2, 3 (non 4).
P. cf. *planus* Siemiradzki. Pl. x, 4.

Subgenus Dichotomosphinctes Buckman

P. luciae de Riaz. Pl. x, 5.
P. elizabethae de Riaz, pl. xii, 4, 5.
P. aff. *elizabethae* de Riaz. Pl. xv, 1.
P. wartae Bukowski. Pl. x, 1.
P. tizianiformis Choffat. Pl. iv, 1.
? *P. antecedens* Salfeld. Pl. xii, 2, 3.
? *P. buckmani* Arkell. Pl. xii, 1 ; pl. viii, 5.
P. pseudocrotalinus Kilian and Guébhard. Pl. vii, 5, 6.
P. sp. Pl. iii, 1, 2 ; pl. iii, 3, 4 (or nuclei of *Perisphinctes* s.s. ?).

Subgenus Perisphinctes sensu stricto

P. sp. nov. aff. *martelli* (Oppel). Pl. ii.
? *P. chloroolithicus* (Gümbel). Pl. xiii.
P. kiliani de Riaz. Pl. iv, 5. (? *P. chloroolithicus* Gümbel.)
P. de Riazi Siemiradzki. Pl. xiv. (? *P. parandieri* de Loriol.)

Subgenus Arisphinctes Buckman

P. plicatilis (J. Sowerby). Pl. i.
P. helenae de Riaz. Pl. viii, 1.
P. treptensis Simionescu. Pl. vii, 1.
P. cf. *kreutzi* Siemiradzki. Pl. vii, 4.
? *P. choffati* de Riaz. Pl. xi, 3.
P. sp. Pl. vi.
P. sp. indet. Pl. ix, 1, 2.

Subgenus Kranaosphinctes Buckman

P. sayni de Riaz. Pl. xv, 5 ; ? and pl. x, 6, 7.
? *P.* sp. indet. Pl. iv, 6.

Subgenus et species indet.

P. depereti de Riaz. Pl. x, 1, 2.
P. spp. indet. Pl. iv, 2–4 ; pl. v ; pl. viii, 2–4 ; pl. ix, 3–5 ; pl. x, 1–2, 8 ; pl. xi, 4, 5 ; pl. xv, 4 ; pl. xvi, 1.

Genus ASPIDOCERAS Zittel

Subgenus EUASPIDOCERAS Spath.

? *A. tietzei* Neumayr. Pl. xix, 5, 6.
A. oegir (Oppel), pl. xix, 7–9.
A. favrei de Riaz. Pl. xix, 10.

Genus PELTOCERAS Waagen

Subgenus GREGORYCERAS Spath

P. transversarium (Quenstedt). Pl. xix, 3, 4.
P. romani de Grossouvre. Pl. xix, 1, 2.
P. riazi de Grossouvre (de Grossouvre, 1917, pl. ix, 10–12).

Genus CARDIOCERAS Neumayr and Uhlig

Subgenus CAWTONICERAS Buckman or MALTONICERAS Arkell

C. sp. Pl. xvi, fig. 7.

Subgenus SUBVERTEBRICERAS Arkell

C. sp. nov. aff. *densiplicatum* Boden. Pl. xvi, fig. 8.

Subgenus indet.

C. sp. indet (nucleus). Pl. xvi, fig. 6.

Genus OCHETOCERAS Haug

O. canaliculatum (von Buch). Pl. xvii, figs. 4, 5, 6.
O. canaliculatum var. *hispidum* (Oppel). Pl. xvii, figs. 2, 3.
O. henrici (d'Orbigny). Pl. xvi, fig. 12 ; pl. xvii, fig. 1.
O. aff. *arolicum* (Oppel). Pl. xvi, figs. 13, 14.

Genus TARAMELLICERAS del Campana

T. bachianum (Oppel). Pl. xvii, figs. 7, 8.
T. cf. *gmelini* (Oppel). Pl. xvii, figs. 9, 10.
T. flexuosum (Münster). Pl. xviii, fig. 2.
T. falloti (de Riaz). Pl. xviii, fig. 3.
T. bukowskii (de Riaz). Pl. xviii, fig. 4.
T. romani (de Riaz). Pl. xviii, fig. 5.
T. spp. Pl. xviii, fig. 1 ; pl. xvi, figs. 15, 16.

Genus LISSOCERAS Bayle

L. cf. *erato* (d'Orbigny). Pl. xvi, fig. 5.

Genus LYTOCERAS Suess

L. cf. *polyanchomenum* Gemmellaro. Pl. xvi, fig. 4.

Genus PHYLLOCERAS Suess

P. mediterraneum Neumayr. Pl. xvi, figs. 9, 10.

Genus SOWERBYCERAS Parona and Bonarelli

S. tortisulcatum (d'Orbigny). Pl. xvi, fig. 11.

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Ring Structures with Carbonate Cores in Southern Rhodesia

By F. P. Mennell

DURING an investigation of the upper part of the Sabi Valley made just before the war in company with my son, the late C. F. Mennell, two well-marked ring structures and indications of others were met with. Reference to these was made in a communication to the Rhodesia Scientific Association in 1938 before the investigation had been concluded or any of the rocks collected had been sliced. The suggestion was then made that they owed their remarkable features to the action of the enclosing granite on the limestone still forming their cores.

Owing to various circumstances directly or indirectly due to war restrictions, microscopical examination of the material was postponed till the opening of the present year. It then became apparent that matters were more complicated than had at first appeared. Nepheline-bearing rocks, not previously recognized in the colony except among some intrusions in the Karroo strata collected by myself in 1940, were detected among the specimens from the Shawa Hills, my friend, Mr. H. B. Maufe, having identified the ijolite before my own specimens were sliced. They have since been located at Dorowa, though by no means so prominent there. A number of modifications have also had to be made in other field determinations. It is evident, for instance, that syenite rather than granite occupies the greater part of the main rings, and some of the granite that does occur in them is related to nordmarkite, while the syenite itself is associated with shonkinite and even more basic types referred to originally as amphibolite, but having in reality pyroxene rather than amphibole as their coloured constituent.

Shawa.—This is situated between the Muwerari and Marobi rivers, close to their confluence. The diameter of the main ring of syenitic rocks is about four miles, but from a distance it looks very much as if the immediately adjacent granite forms part of the structure. The latter in any case differs markedly from the ordinary " Old Granite " near the Muwerari. Both here and at Dorowa, which has been much more closely investigated, poor exposures prevent any definite line of demarcation being laid down between the granite and syenite, if, indeed, any exists, as at Dorowa granite clearly forms part of the predominantly syenitic ring. Most of the way round, the outer ring of the Shawa Hills consists chiefly of syenite, interrupted and at times veined by a dark pyroxenite, made up almost entirely, as seen under the microscope, of a deep green pleochroic aegirine-augite like that in the syenite itself. This passes into a kind of shonkinite owing to increase in the amount of felspar present. On the west and south-west, however, there is a great mass of ijolite, merging at times into something very like jacupirangite, as though poor in magnetite, it has subordinate biotite and nepheline with the predominant pyroxene. These rocks appear to form a crescent-shaped body two miles or more in length, no signs of them having been seen on the north or east either by myself or Mr. Tyndale-Biscoe of the Geological Survey, who visited the locality in 1941. He has kindly shown me his notes, which are confirmatory of my own observations. The pyroxene of the jacupirangite and of the

normal ijolite is less deeply coloured and pleochroic than that of the nepheline-free syenite and pyroxenite forming the greater part of the outer circle elsewhere.

The core of the whole structure appears to be entirely composed of limestone, or perhaps one should rather say carbonate rock, both because of its uncertain origin and the fact that it is very far from being reasonably pure calcium carbonate. Very little of it is soluble in cold dilute acid. It varies much in grain, and, though it usually consists essentially of dolomite and other carbonates, it shows in places an appreciable amount of magnetite, sometimes in large crystals. Elsewhere it contains quite a quantity of apatite, though this is only recognizable under the microscope. The rock often has a distinct bedding or banding with a N.W.–S.E. or W.N.W.–E.S.E. strike. It occupies an area about two miles across, and may be nearly circular in outline if it occurs on the low ground to the north-east, as is probably the case.

The carbonate rock is completely surrounded by serpentine as far as could be ascertained, and does not therefore come into direct contact with the outer syenite. The serpentine, which sometimes shows seams of magnesite, forms low ground on the south, but rises into conspicuous hills on the north of the limestone. It includes, at a point south-east of, and perhaps touching the carbonate rock, a mass of pure olivine-rock, or dunite, the absolutely unaltered condition of which strongly suggests a late period of intrusion.

At this early stage it is not intended to go into details regarding the petrography of this remarkable complex, which it is hoped to do at a later date. It will be evident, however, that it comprises rocks which are commonly regarded as the poles asunder on any theory of magmatic differentiation. They not only range, in fact, from acid to ultra-basic, but from extremely alkaline to absolutely alkali-free types. If the carbonates are accepted as igneous, in accordance with the views of some observers, they even provide examples of non-silicate-bearing types, and such certainly exist at Dorowa, quite apart from the carbonates, as will be seen below.

Dorowa.—The structure marked by the Dorowa Hills is considerably smaller and less complex than that of Shawa. The eastern edge is not much more than a mile from the Sabi River, and is about three miles below its confluence with the Ruwenji, its most important tributary on the right bank up to that point. The hills are rather less than two miles from north to south, and about a mile from east to west, arranged like a horseshoe with an opening to the south. It is evident, however, that the syenite extends on to the low ground beyond them to the west, and perhaps also to the east, so that its outcrop may be nearly circular, as at Shawa. Though much the most conspicuous member, the syenite is by no means the only component of the ring round the carbonates, but there is no intervening serpentine here. Granite can be seen at a number of points. Some approaches nordmarkite in character, but some closely resembles the surrounding mass that extends at least as far as the Ruwenji. Biotite may be the only dark constituent, but pyroxene often occurs as well. It is of the usual deep green variety, as seen under the microscope, and the clusters of small crystals that may be observed surrounding partly resorbed

biotite flakes indicate that it originated as a reaction product of that mineral. Some of the granite contains ordinary microcline and a good deal of plagioclase, but some is extremely rich in quartz in spite of the fact that it contains the green pyroxene and the same anorthoclase-like variety of felspar as in the syenite. The latter is often interrupted and veined by pyroxenite or shonkinite, especially on the outer edge, and it also shows occasional veins of lestiwarite and even aplite that appear to be older than the pyroxenite. Basic varieties of the syenite, merging into shonkinite, are found, as well as nepheline-bearing rocks, of which the extremes belong to the urtite-ijolite group. In these the pyroxene has the same characters as in the granites, and it is regrettable that poor exposures prevent the relations of these various types of rock from being accurately determined.

The carbonate core, which is here about 500 yards across, has the character, in most of the few exposures, of the fine-grained dolomitic type seen at Shawa. What appears to be the eastern margin of the main mass, has, however, at its north end, a series of types of rock varying much in grain and often ferruginous, which resemble vein matter rather than either sedimentary or metamorphic materials. A detached outcrop at the base of the small hill at the north-east end of the main structure has a metamorphic appearance, being strongly foliated, and only distinguishable from gneiss by its softness. It is coarse-grained, and in places contains both magnetite and an asbestiform iron-amphibole as well as small flakes of mica. It has a north and south strike. Two other detached carbonate masses occur at the southern end of the structure.

A point of special interest, and also of economic importance, is the occurrence of rocks, other than the carbonates, belonging to the rare group that have no silicate minerals among their essential constituents. The most conspicuous of these is magnetite rock, sometimes merging into solid masses of magnetite containing about 69 per cent of metallic iron. The largest of these, situated in the S.W. portion of the syenite ring, is a lenticular mass about 40 feet in maximum width and two to three hundred yards in length. Magnetite debris derived from less massive bodies occurs all round the structure. A rough estimate indicated that a million tons of it could probably be collected without much trouble, and there are ancient workings in it where the accumulations are thickest.

The chief impurity in the magnetite bodies is apatite, and they grade into apatite rock with magnetite only present as a minor accessory. Nepheline, pyroxene, mica, and felspar occur in places as subordinate constituents. Though much more abundant than the magnetite bodies, the apatite rock is so fine-grained that it is not easy to recognize as it looks very much like decomposed pyroxenite. The average grain-size is, in fact, less than one hundredth of an inch, and as it is commonly silicified and to some extent impregnated with iron oxides where it outcrops, its true nature only became apparent under the microscope. In its fine grain and other respects it evidently resembles very closely the Russian occurrences of the Kola Peninsula, though magnetite appears to be decidedly more conspicuous than at that locality. Pyroxenite, etc., penetrates the apatite rock in places.

Origin, etc.—The preceding notes have been put together, before a

systematic investigation of the petrology has been possible, owing to the interest attaching to the problem presented by the carbonate masses. It will be evident from the outline that has been given that the ring-structures here have strong relationships not only to the presumably volcanic occurrences further north in various parts of tropical Africa, but to the more deep-seated types such as that long ago described by Shand from Sekukuniland in the Union of South Africa. They also form a link between these and the various North European complexes without carbonate cores, like that of Iivaara in Finland (*fide* Shand) which also ranges from ijolite to granite, and that of Kola with a less extended range but containing apatite-rock. In the last instance the suggestion of origin from reaction with limestone is rejected by Figov, largely, no doubt, on account of the absence of any relic of carbonates, so their occurrence here is particularly interesting, and the theory has certainly still to be reckoned with. It may be noted that nothing in the shape of volcanic material occurs in the neighbourhood, and the rocks have on the whole a decidedly plutonic aspect.

With regard to the age of these remarkable structures there is at present little definite evidence. As already indicated, the granite surrounding the syenitic rings is a fine even-grained rock quite different from the "Old Granite" seen in the bed of the Sabi River, which has a decidedly gneissic aspect. If it were certain that it was of the same age as that forming an integral part of the ring structures the matter might be taken a step further, as it is penetrated by dolerite dykes and sheets almost unquestionably of late Karroo, i.e. early Jurassic age. It must be admitted that the resemblance of these acid rocks is sufficiently great to make a strong case for their being referred to the same (pre-Karroo) period of intrusion. On the other hand, nepheline-bearing rocks of similar composition to those in the rings are known penetrating the Karroo beds away to the south, and show the same freedom from plagioclase felspars, a feature they share with the post-Karroo Lupata lavas along the Zambesi, first described in this Magazine for 1922 by the present writer. The extreme freshness of some of the rocks, such as the Shawa dunite and ijolite, certainly favours the later date, but the question must remain open until further evidence is accumulated.

The Physiographical History of Western Szechuan— A Review and Discussion

By H. B. Whittington

RECENT writings by Cotton (1944, 1945) and Richardson (1945) have drawn the attention of geologists in this country to the Pleistocene history of West China, and in particular to the river terraces and their mode of formation. Harland has now re-stated the problems of the physiographical history of Western Szechuan, and drawn attention to the gaps in our knowledge. This paper [1] is both complementary and supplementary to that of Richardson (1943 ; reviewed by Cotton, 1944). During the past two years I have had opportunity to study the geomorphology of the Border Ranges of north-western Szechuan, and this review is, therefore, accompanied by a discussion of certain points in the light of my own findings and the work of other writers.

Review

Harland adopts the convenient division of Western Szechuan into the Red Basin (with the Chengtu Plain) and the Border Ranges on the west and north-west. Under *observed processes* he notes the great erosion that occurs in the Border Ranges after heavy rains. At high altitudes frost-splitting and solifluction are important. Man's activity is also effective in hastening erosion by " removing the protective cover of vegetation ". Deposition occurs along stream courses, including the accumulation of dunes of blown sand derived from river beaches. Periodic dust storms occur in the Red Basin. At high altitudes deposition by melting ice occurs, and there is " slow accumulation of swamp vegetation " in glacial valleys. " Man is active in countering the effects of soil erosion with partial success " through terracing, which results in deposition. This effect is most notable in the irrigation system of the Chengtu Plain, where " a rapid accumulation of six inches in a century " is suggested. Earthquakes, their epicentres usually in the Border Ranges, frequently occur, and sometimes set in motion landslides. There are no systematic records of climate. The contrast between the cloud cover over the Red Basin, especially the Chengtu Plain, and the clearer air of the Border Ranges, is noted. The western sides of the Border Ranges are drier, apparently " due to loss of moisture from the summer monsoon winds as they cross successively higher ranges ".

Significant morphology begins with a consideration of river valleys. In the Border Ranges structural control is marked, but notable by its absence in the Red Basin. The " uniformly steep-sided, often very deep " valleys of the Border Ranges show a " total difference of relief of between five hundred and two thousand metres" and, " In most cases the valley bottoms expose solid rock at the deepest point.... In longitudinal

[1] The Physiographical History of Western Szechuan, by W. B. Harland. *Journ. West China Border Research Society* (*Chengtu*), xv, Ser. B, 1–19, 1945. The available numbers of this Journal may now, through the good offices of the British Council, be obtained from Longmans, Green and Co., London.

profile rough measurements show extremely high gradients," e.g. in the Border Ranges from 1 in 24 to 1 in 180, as compared to 1 in 400 in the Chengtu Plain. " It is clear . . . that the higher reaches of these rivers are not graded."

Harland states that " the word ' terrace ' has been defined in morphological terms ". He points out that " Some confusion has resulted in so far as a terrace essentially records the discontinuity between two conditions ". The first is " a relatively constant level " which " may represent a time of lateral erosion, deposition, or both ", followed by the cutting of " a steeper slope " indicating rejuvenation. He urges a distinction between these two elements to avoid ambiguity in the interpretation of terraces " in terms of climatic stages ". " The significant feature of an erosion or deposition surface is its base level " and " On this basis the distinction between false and true terraces (Hanson-Lowe, 1939) is seen to be one of degree rather than kind ". The heights of various levels in the Border Ranges and Red Basin, above the nearest main river flood plain, are plotted. These " data show the relics of a peneplain or surface of mature erosion at about 160 metres, and there are subsidiary stages of levelling between this and the High Terrace of Richardson (1943). The latter, together with his Middle and Low Terraces, are more prominent members of a larger series which can be correlated with certainty over quite large areas ".

Typical valley glacier topography occurs in the Border Ranges, Kangting area, at heights above 3,200 metres. In the hills of the Red Basin north and east of Chengtu, at heights between 450 and 700 metres above sea level, the occurrence of biscuit-board topography is described and sketch maps are given. The occurrence of badland topography and rounded rock surfaces in the Red Basin is noted, and the effects of structure upon land-form.

As *distinctive deposits* the following are enumerated : Chengtu Clays (supposed to be weathered loess deposits), terrace gravels at three levels, boulder clays, solifluction deposits, talus, developed and undeveloped soils. Notable are the weathered " boulder clays " in the foothills of the Red Basin, the occurrence of sub-lateritic soils in the Red Basin " associated with the higher terrace deposits ", and the presence of B-horizons of sesquioxide enrichment in certain soil-profiles in the Border Ranges.

The data are thus summarized, and in seeking to interpret these data Harland discusses the working of various physiographical processes. As to running water, he would stress that " An increase of load carried by the water might exceed the capacity of the increased volume due to greater precipitation. Thus higher rainfall would cause aggradation in all but the uppermost tributaries and hill slopes. On these slopes solifluction would be a powerful factor in loading the streams . . . sediment production is dependent on precipitation and increase of gradient through uplift " and, following Paterson (1941) " Sediment production, not sediment deposition, is therefore the primary datum in correlation ".

The author states that " it seems clear after critical study that the cirque topography described above [i.e. the biscuit-board topography of the Red Basin] is due to " snowpatch and corrie glacier erosion.

"Crustal adjustments are thought to have been active even up to the present date. . . . Uplift due to erosion of the mountains" is "extremely important . . . so that correlating levels between the Red Basin and the Border Ranges becomes extremely difficult". Orogenesis "has clearly played a leading part in bringing the snow-peaks to their present great height. It would seem to have a causal relation to the formation of the Chengtu Plain, as well as the Red Basin". An important result of this is that "Where uplift has taken place, erosion has been active, and thus much less of the early condition remains; in other words, one would expect to find the oldest land-forms in the [Red] Basin".

"The variety of soils already enumerated may largely be attributed to weathering under existing conditions" but "There is no zone [of present soil formation] to include the sub-tropical partial lateritic soils, which lack indicates a change of climate. There is no extensive formation of loessial soils, only their reduction by weathering, which indicates that at one time a drier climate obtained". The rotten "boulder clay" may indicate "weathering at a higher temperature", while certain yellow earths of the Red Basin may have "been formed under cooler conditions than now". The rounded rock surfaces of the Red Basin may have originated by "exfoliation due to daily extremes of temperature" and this suggests that "clearer skies, and probably desert conditions, have prevailed not too long ago". On the other hand, some "may conceivably be roches moutonnées". The activity of man in terrace building, and thus effectively eliminating natural drainage in the valleys of the Red Basin, is noted. In addition the hills are cut into by the hoe, and it is considered whether these activities of man would account for the biscuit-board topography. This hypothesis is rejected.

In West China, as Harland states, "Sufficient evidence is given to show that climate has not been uniform during the formation of our landscape." In seeking to account for this climatic variation, various theoretical causes are examined—polar migration, lowering of sea level, and Paterson's (1941) suggestions "that a glacial period is closely associated with both cold deserts and warm floods". A notable contribution is Harland's consideration of the continental situation of this region. He points out that a lowering of temperature or a lowering of sea level, or both together, would accentuate this continental effect. Thus "ice held in these interior glaciers may never have been large in bulk, being starved of snow rather than limited by warmth". Therefore "It is likely that when it was cold enough to cause cirque glacierets in the [Red Basin] there was not enough precipitation for any extension of an ice sheet in the mountains. It is even possible that cirque glaciation in the Red Basin did not correspond to a maximum glaciation in the mountains, and certainly not to the extensive gravel deposits. On the other hand it is not at all certain that the differences of elevation in those days were of the same order as now".

An "almost entirely speculative" attempt "to crystallize the problem in stratigraphical form" then follows. We may note that "at least four glaciations are postulated". Warm periods are regarded as the times of formation of terrace levels, lateritization, and loess weathering: cold periods as times of terrace face cutting, the Red Basin and other glaciations, and loess deposition. "The crux of the problem lies in

the lack of stratigraphical evidence for correlating erosional features on the one hand, with water-laid gravel deposits on the other."

The concluding bibliographical discussion gives a valuable list of relevant writings.

Discussion

Of outstanding interest is Harland's new evidence of low-level glaciation in the Red Basin. As he points out, J. S. Lee is the pioneer in describing glaciation at low levels in China, and other Chinese geologists have recently described new areas in Hupeh and Kuanghsi. Thus additional evidence of these earlier glaciations is being accumulated, including Richardson's (1943 ; Cotton, 1944, p. 272) possible Omei glaciation, in the Border Ranges at about the 1,000-metre line.

Recent glaciation at high levels, over 11,000 feet, has been recognized in only a limited region in West China. Elsewhere in the Border Ranges, at heights ranging from 5,000 to 12,000 feet, traces of the work of ice are absent or inconspicuous (Harland, p. 10 ; Whittington, 1944, pp. 18–19). Two factors may account for this, as Harland suggests, (*a*) Pleistocene uplift and erosion have caused the removal of all traces of ice action. (*b*) During cold periods the mountains may have been dry. There is the additional complication in correlation in that high and low-level glaciations may not have occurred at the same time.

The evidence for climatic oscillation during the Pleistocene in West China has been both added to and clarified by Harland. Similar evidence of climatic change has long been known in other parts of China (Lee, 1939, ch. ix), but correlation between widely separated areas is hampered by differences in interpretation and lack of palaeontological data. The distance of the West China region from the sea may not only have accentuated the continental climatic conditions, but may also have " insulated " the rivers from the effects of changes in the relative levels of land and sea (compare Richardson, 1945, p. 18, and Harland, p. 14). It would seem, in view of this continental situation, that Harland is correct in associating increased precipitation with warmth, and not, as Richardson suggests (see Cotton, 1945, p. 10) with colder conditions.

I have briefly (1944) described certain river terraces in the Border Ranges and further information is given in a second paper, also to be published by the Geological Survey of Szechuan. They are well developed in main and tributary valleys, occurring at a variety of heights. General terrace levels can be distinguished along considerable stretches of individual rivers, at 10 to 20 feet, 30 to 50 feet, one or two at heights between 80 and 150 feet, in places one at 250 to 300 feet, and in certain localities gravels and terrace fragments occur at heights of 500 to 700 feet above the present river level. The terraces are best developed at the junction of main and tributary streams, and at these points the higher terraces have a composite alluvial fan-form, descending from the tributary valleys to fan out over the main stream. Along the main stream also, particularly the higher terraces have an alluvial fan-form, descending from tributary gullies. The transverse profile of these terraces is thus not horizontal, but slopes riverwards. The terraces are usually built of coarse rounded gravels and

sand, but the rock fragments are sometimes angular, particularly in the neighbourhood of tributary gullies. The faces of the terraces show that they are not always entirely built of gravels but sometimes partly, or even wholly, of solid rock. At scattered localities the lower terraces at 10 to 20 feet, and rarely 50 feet or more, are cut in solid rock, with or without a gravel cover. It may well be that certain of the lower terraces have been formed by the redistribution of material during the dissection of the higher alluvial fan-form terraces. Braiding becomes conspicuous in these rivers as they pass through the foothills and emerge on to the Chengtu Plain, and after heavy rains the whole width of the river bed is occupied. The terraces nowhere have the appearance of being an infilling of valleys more deeply excavated than the present ones, for solid rocks frequently outcrop in the river bed. It does not seem that these alluvial fan-form terraces can be ascribed to the covering of a more " normal " type of terrace (i.e. with a horizontal cross-profile) by superficial deposits.

Much work yet remains to be done on these terraces, and in particular full description awaits the making of accurate contoured maps. I believe, however, in common with Richardson and Harland, that at least some of these terraces are aggradational, and one of the results of Pleistocene changes in climate. With increased rainfall, in this mountain region with steep-sided valleys and great differences of relief (2–7,000 feet) between divides and valley bottoms, erosion and mass movements of the mantle would supply a load beyond the capacity for transportation of the increased volume. Deposition of alluvial fans would occur at the mouths of tributary streams and gullies, especially marked at the main junctions. With decreased precipitation, and thus decreased load, the far from graded streams would commence to dissect the fans.

Modern textbooks on geomorphology do not seem to recognize terraces originating in this way. Barbour (1935) and Hanson-Lowe (1939) observed these terraces in various parts of China, and commented on their distinctive form, including the variation in height of the face with dissection, the concave cross-profile, and the absence of a sharp discontinuity of slope at the rear. Hanson-Lowe proposed the term " false " for these terraces, and regarded them as " neither interesting nor useful " in " helping to elucidate the earlier history of the river "—in this case, the Yangtze (1939, in discussion, p. 66). The term " false " does not seem particularly suitable, unless a rather narrow view of what constitutes a river terrace is taken. It is evident that these terraces have significance as clues to the physiographical history of Western Szechuan. This distinctive type, " due to climatic oscillation," to use Cotton's phrase (1945), may well occur in other parts of the world.

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Geological Research in Holland During the War Years

We have received the following list of geological memoirs which have appeared in Holland during the years of the German Occupation, and feel that its publication would be of considerable interest to British geologists.

During the war the Directors of the Netherlands Coal Mines had given to a number of young geologists the opportunity for geological studies at both Institutes of the Geological Foundation (Geologische Stichting), the Geological Bureau, Heerlen, and the Department of Geological Maps, Haarlem.

They also made it possible to publish the results of these researches, as a series of memoirs (Series C of the memoirs of the Foundation).

The series contains the following sections :—

- I. Tectonic Papers : 1, Macrotectonics ; 2, Microtectonics ; 3, Geophysics.
- II. 1, Palaeogeography ; 2, Petrography.
- III. 1, Palaeobotany ; 2, Research on Coal.
- IV. Palaeontology : Macrofauna ; 1, Tertiary ; 2, Mesozoic ; 3, Carboniferous.
- V. Palaeontology : Microfauna.
- VI. Miscellaneous studies.

Memoirs published :—

		Price. f.
I, 1, No. 1.	A. J. DIKKERS. *Geology of the Colliery Maurits* . .	
I, 1, No. 2.	J. E. MULLER. *Post-carboniferous Tectonics of the S. Limburg coalfield*	
I, 2, No. 1.	J. M. DEENEN. *Fractures in coal and rock* . . .	6.25
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II, 2, No. 1.	N. HEERTJES. *Petrological Investigations of the Coal-Measures sediments of South Limburg (the Netherlands)*	4.00
II, 2, No. 2.	J. E. MULLER. *Sedimental petrology of the younger deposits in S. Limburg*	6.75
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IV, 1, No. 1.	C. IJSPEERT. *Monographie der miozänen taxodonten Bivalven aus dem Peelgebiete (die Niederlande)* . .	3.50
IV, 1, No. 2.	J. HEERING. *Die oligocänen taxodonten Bivalven aus dem Peelgebiete (die Niederlande)*	2.75
IV, 1, No. 3.	J. C. H. ALBRECHT und W. VALK. *Oligocäne Invertebraten von Süd-Limburg*	9.25
IV, I, No. 4.	J. HEERING. *Die oberoligocänen Bivalven (mit Ausnahme der Taxodonten) aus dem Peelgebiete (die Niederlande)*	4.75
IV, 1, No. 5.	J. H. VAN VOORTHUYSEN. *Miozäne Gastropoden aus dem Peelgebiet (Niederlande) (Rissoidae-Muricidae, nach Zittel's Einleitung* 1924)	7.75
IV, 2, No. 1.	W. J. M. VAN DER WEIJDEN. *Die Macrofauna der Hervenschen Kreide mit besonderer Berücksichtigung der Lamellibranchiaten*	7.50

		Price. *f.*
IV, 3, No. 1.	S. VAN DER HEIDE. *Les Lamellibranches limniques du terrain houiller du Limbourg du Sud (Pay-Bas)* . .	5.25
IV, 3, No. 2.	S. VAN DER HEIDE. *La faune ichthyologique du Carbonifère supérieur des Pay-Bas*	4.00
IV, 3, No. 3.	L. DORSMAN. *The marine fauna of the Carboniferous in the Netherlands*	
V, No. 1.	TH. REINHOLD und A. TEN DAM. *Die stratigraphische Gliederung des Niederländischen Plio-Pleistozäns nach Foraminiferen*	5.00
V, No. 2.	TH. REINHOLD und A. TEN DAM. *Die stratigraphische Gliederung des Niederländischen Oligo-Miozäns nach Foraminiferen (mit Ausnahme von S.-Limburg)* . .	5.25
V, No. 3.	A. TEN DAM. *Die stratigraphische Gliederung des Niederländischen Paläozäns und Eozäns nach Foraminiferen (mit Ausnahme van Süd-Limburg)* . . .	7.00
VI, No. 1.	J. W. R. BRUEREN. *Les terrasses de la Meuse dans le Limbourg du Sud*	9.00

Memoirs in the press :—

H. G. J. SAX. *Tectonics of the Limburg Coalfield.*
S. J. DIJKSTRA. *Megasporen aus dem Karbon von Süd-Limburg.*
S. V. D. HEIDE. *Études paléontologiques et stratigraphiques dans le Bassin du Peel.*
C. BEETS. *Plio-Pleistocene Gastropods.*
J. HEERING. *Tertiary Lamellibranchiates.*
T. B. HAITES. *Correlation and Parallelization of the Coal-seams of the Netherlands and adjacent regions.*

Other memoirs are in preparation.

The prices mentioned in the list are those fixed for the whole series. Separate numbers are 20 per cent more.

Orders can be placed at the Geologisch Bureau, Heerlen, Akerstraat 86–88 ; Geologische Stichting, Geologische Kaart, Spaarne 17, Haarlem ; and at the printers, E. v. Aelst, Witmakerstraat 25, Maastricht.

ERRATUM

Etruria Marls of N. Staffordshire, by W. O. Williamson, *Geol. Mag.*, lxxxiii, 1946, p. 23, line 25, *for* quartz veins *read* quartz grains.

CORRESPONDENCE

ON ALGAL LIMESTONES AT THE BASE OF THE BURDIEHOUSE LIMESTONE, NEAR BURDIEHOUSE, MIDLOTHIAN

SIR,—Although the occurrence of algal limestones at the base of the Burdiehouse Limestone at several localities in the Central Coalfield of Scotland has been known for many years, curiously enough their presence has never been observed in the type district near Edinburgh. We therefore desire to record that this gap in our knowledge has now been filled. During a recent visit to the mine at Straiton, near Burdiehouse, we found large blocks of algal limestone on the waste-heap, and on inquiry we learned that they had lately been removed from the floor of the Burdiehouse bed during road repairs in the underground workings.

The algal limestones here are in two layers, each being slightly less than one foot in thickness, and separated by a conspicuous sun-cracked bedding plane. The lower bed which rests on a yellowish sandstone, also exhibiting numerous sun-cracks, is made up of small round algal bodies resembling oolite grains, and associated with them are large sphaeroid masses showing the characteristic structure of Spongiostromids. The upper layer is a dark grey reef-like limestone displaying a similar concentric structure, and has a smooth or warty bulbous exterior, identical in appearance with that of the equivalent bed at Rosyth and other places in the coalfield. Dr. F. W. Anderson, who has kindly examined some of the specimens submitted by us, reports on them as follows :—

" Similar algal concretions to the small oolite-like bodies are found in the Pennsylvanian of North America. They have been given the generic name of *Osagia* by Twenhofel.

" The large spheroidal masses resemble very closely the algal genus *Ottonosia* Twenhofel, though here, as in other localities in Scotland, they show some features characteristic of the genus *Callenia*, Walcott."

The specimens are now preserved in the collections of the Geological Survey in Edinburgh.

W. Q. KENNEDY.
J. PRINGLE.

16th January, 1946.

ON THE NORMAL FAULTING OF RIFT VALLEY STRUCTURES

SIRS,—I was much interested in Dr. Dixey's letter in the May–June number of the *Geological Magazine* for 1945. If there are clear sections in the Northern Frontier Province of Kenya, showing a transitional zone between the Jurassics and the Marehan Sandstone, the latter must be of Cretaceous Age. Our expedition was a reconnaissance only, and these sections were missed. It is possible that there are two sets of scarp-forming sandstones, one above and one below the Jurassic marines, for the Wergudud Range shows all the characteristics of a fault-scarp.

With regard to Dr. Dixey's remarks on " residuals ", some confusion of thought is bound to arise on account of the impossibility exactly of defining respectively fault-scarps, fault-line scarps, and residuals, and where the one begins and the other ends. In my own writing I would not use the term " residual ", except in regard to a mass which stands above the peneplane by virtue *only* of its greater hardness, that is a mass left upstanding above the peneplane by circum-denudation only. I would not apply it to a mass, which has been originally uplifted above the peneplane, however greatly diminished by denudation it may have become. And surely it is more logical to confine " fault-line scarp " to a scarp formed by the differential erosion of two rock masses thrown into juxta-position by a fault. As such the term is defined in most text-books, and, as such, fault-line scarps are generally easy to distinguish.

There seems to be a tendency to regard difference of level alone as indicating different cycles of erosion, though other evidence than this is really required as well. The multiplication of erosion cycles leads to the conception of long periods of rest, interrupted by short periods of movement. Dr. Dixey distinguishes between the peneplane of the Northern Frontier Province and the " main peneplain (*sic*) ", and states that the former " belongs to a much younger cycle, which is separated from the main peneplain by scarps up to 1,000 feet in height, that are usually erosion scarps, but sometimes possibly fault-line scarps ". I suggest that his " fault-line scarps " are greatly eroded fault-scarps, and, where not so, are not scarps due to erosion only, but upwarped slopes in process of denudation. A difference of level between two plateaux is no proof in itself of two erosion cycles and of two peneplanations. If, in East Africa, it is supposed that there were several peneplanations between the movements, that have undoubtedly occurred, where has the enormous resultant mass of material been deposited ? There is no sign of it off the East Coast, where depths fall rapidly to 10,000 feet. Along the sides of the rift valleys, and especially in the region of the great trough lakes, there is often a multiplication of different levels. Are not these all part of the same peneplane lowered to different levels at different times ?

Surely the general conception of one Central African peneplane, dating at least from the Jurassic, and since either raised or lowered gradually along different lines, or warped up to different levels, at varying rates in different districts, there being at no time long periods of rest, surely this conception is more consonant with the physiographic evidence.

It would be of the greatest interest if the Geological Surveys of Kenya, Uganda, Tanganyika, and Rhodesia, were jointly to produce a map, say on a scale of 1:1,000,000, giving form-lines of all the physiographic data so far collected, and, where necessary, leaving blanks for the addition of data from future papers. Volcanoes and their modification of the physiography should also be shown. The writer has attempted to draft such a map from the existing 1:1,000,000 sheets, and from papers so far published, but there is considerable difficulty in reconciling the various projections used, and there are often undoubted errors, possibly in printing, even in the publications of the learned societies, errors which render the ready use of the pantagraph impossible. As an example at random, Dr. Dixey's map, accompanying his " Early Cretaceous Valley Floor

Peneplain of the Lake Nyassa Region "[1] shows the lines of longitude spaced further apart than the lines of latitude !

The geological surveys of the respective territories have, however, most of the original data, and a general map with sufficient detail would bring out many points of interest. One of these, which may be generally characteristic of rift valley structures, and which, we believe, has not so far been remarked upon, is the existence in the rift region of triangular upthrown blocks, apex pointing south, and with dip-slope to the north. There is a possible connection between these and the often remarked southward pointing apices of the continents, and, if so, the rift region may hold the key to the solution of the figure of the earth. The Sinai Peninsula is the most obvious example, and this is rather like a small-scale India in structure, apex uplifted and pointing south, a gentle dip to the whole peninsula and its strata to the north, and with east and west folding parallel to the shore of the Mediterranean in the north. In Tanganyika, the block with the mountain Mbeya as the southward pointing apex, and the Rukwa and Ruaha troughs as the sides is another example.[2] And again the block bounded by the submarine trough off the Mombasa coast (Ruvu-Mombasa Fault) on the one side, and on the other the Pangani Valley under the Pare-Usumbara Ranges, with the southward pointing apex south-east of Tanga, is a similar structure.[3]

This is an intriguing matter, which can only be brought out with good physiographic surveys and good general maps.

H. G. BUSK.

LYMINGTON,
HANTS.

[1] *Quart. Journ. Geol. Soc.*, xcv, 1939, plate iv.

[2] Bailey Willis, East African Plateaus and Rift Valleys. *Carnegie Inst. of Washington.* Plate viii.

[3] *Op. cit.*, plate vi.

REVIEWS

ROCK WOOL. By E. M. GUPPY and J. PHEMISTER. Spec. Rep. Min. Res. Vol. xxxiv. *Mem. Geol. Survey*, pp. ii + 46. H.M. Stationery Office, 1945. Price 9*d.*

Rock wool, an excellent insulator for heat and sound, is analogous to glass wool and slag wool, but is made from natural rock. It is essentially a lime or lime-magnesia glass, usually with some iron, alumina, and other bases. It is made by blowing a strong blast of air or dry steam through a stream of the molten rock.

A wool rock can only be defined as a rock suitable for making wool; from the facts as to composition stated above it is obvious that the composition of a wool rock must be essentially a siliceous limestone or dolomite. In practice the material usually employed appears to be a mixture of limestone or dolomite and shale, to give the necessary silica, if the calcareous rock is too pure to be used alone. A large part of this memoir is occupied by a list of suitable rocks from localities in the British Isles; many of the descriptions are extracted from old memoirs, and it may be noted that in the case of some examples personally known to the present writer, especially in the Yorkshire Jurassics, the present tense is used in describing old workings abandoned fifty or more years ago and now hardly identifiable.

THE CHARNOCKITE ROCKS OF MYSORE, SOUTHERN INDIA. By B. RAMA RAO. pp. iv + 197, with maps and plates. Bulletin 18, Mysore Geological Department, Bangalore, 1945. Price 3 rupees.

Since the author of this interesting memoir very wisely provides an excellent summary of his conclusions, we cannot do better than give here a condensation of this, noting first that the Mysore rocks form a direct northern continuation of Holland's original type area. As a result of twenty-five years' work it is concluded that the charnockites of Mysore have been formed mainly by the re-crystallization—from repeated metamorphism and granitization—of a complex series of rocks of diverse types and different modes of origin and age-relations. A composite series of impure ancient sediments have given rise to hypersthene-granulites, corresponding to the acid, intermediate, and basic divisions, as originally described, while crystallization-differentiation of contaminated sheets and sills of basic rocks intruded into such sediments gave rise to granulitic norites, hypersthene-gabbros, and pyroxenites like the basic and ultrabasic charnockites. From the reaction of alkaline granitic fluids on basic rocks, and from the assimilation of such rocks by granites were formed intermediate and acid charnockites.

These results are important, tending to show that it is no longer possible to regard hypersthene-bearing rocks, especially the acid ones, as of pure magmatic origin.

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Bedding-faults and Related Minor Structures in the Upper Valentian Rocks near Aberystwyth

By H. P. Lewis

During recent years much attention has been given to the recognition of rock-structures which have been produced by the slumping and sliding of bedded deposits on the sea-floor during or soon after their accumulation, but as it is often difficult to distinguish between structures so formed and those which are the result of tectonic movements which occurred long subsequent to the deposition and consolidation of the rocks affected, it is my purpose to record certain minor bedding-structures which clearly owe their origin to such later tectonic movements in the hope that structures of this origin may more readily be distinguished from those produced by slumping.[1] It is true that the occurrence of movements parallel to the bedding is suspected to have been widespread, and, among others, Boswell, Cobbold, and Greenly have recorded examples from this country (1937, 1904, 1919), yet, because of the general scarcity of direct evidence whereby the magnitude and frequency of such movements can be proved, it would seem to be of importance to describe the structures when the evidence of their later origin is manifest. It is for this reason, and with a view to supplementing the very little information on this topic usually contained in works on structural geology, that it has been thought advisable to make known some of the details of the minor bedding-structures which are visible in particularly instructive outcrops in the cliffs and on the foreshore of the coast of North Cardiganshire.

Most of the minor structures here described occur in association with folds, faults, and thrusts of larger scale. Some of these relatively major structures were evidently produced by disturbances and dislocations that were approximately contemporaneous with those giving origin to the minor bedding-structures, and, in many instances, the latter may be regarded as having been produced by movements of adjustment, related to and consequent on the major disturbances. In other cases, large scale, associated, transverse dip-faults and thrusts are definitely of later origin than the minor structures, but it is often difficult to determine whether a transverse outcrop of faulted and confused rock has been moved by later bedding-slip when the latter is of small extent.

[1] For a proposed classification of bedding-plane movements see Behre (1937).

In the rocks examined, which are of Upper Valentian age and include the Aberystwyth Grit Group, the banded or "patterned" nature of the mudstones and the alternations of the mudstones with thin grit bands have proved helpful in assessing the magnitude of the smaller displacements. Pseudo-rippling, rhomboid jointing of the grits and fracture-cleavage of the mudstones give evidence of compression. The plication of veins parallel or nearly parallel to the bedding, slickensides on the bedding surfaces, bands of gouge-like rock in the mudstones and, probably, the peculiar chatter-marks described by Challinor and Williams (1926), all indicate differential movement along the bedding-planes, but the chief direct evidence concerning the characte· and extent of the bedding movements has been derived from an examination of the dis-displacements of transverse quartz-veins, minor cross-faults, and joint-planes.

Slickensides and Crumpled Veins Parallel to the Bedding

The presence of an abundance of slickensided bedding-surfaces is the most conspicuous and widespread indication of the occurrence of differential movements between successive beds in the Aberystwyth Grits. Bedding surfaces with parallel close-set striations extending for several feet are common, and they can be easily studied on freshly fallen blocks of grit at the foot of the cliffs. The grit surface usually has a thin veneer of mudstone on which the striae are well marked, but slipping between beds of mudstone tends to produce a glazed surface rather than a striated one.

Some of the mudstones are banded or "patterned" by thin pale layers of softer rock. It can frequently be observed that slipping has occurred at the level of these thin bands, so as to suggest the possibility that they are layers of gouge-like material produced by differential movement between adjacent beds of normal mudstone. But, on the other hand, it is often the case that no obvious bedding movements have coincided with these paler bands, so that if differential movement between the beds contributed to their formation, it must have pre-dated the movements which are here being considered.

The infiltration of siliceous solutions and the deposition of quartz have been of frequent occurrence along the slickensided planes of movement. Such planes are found to be characterized either by a single vein or by schist-like layers composed of alternating films of quartz and indurated mudstone up to two inches in composite thickness. In a composite vein exposed in the cliffs and on the foreshore south of Borth, and which can be traced for at least fifty yards, the displacement of a small transverse fault show that the slipping along the bedding apparently has not been more than three inches since this fault was formed, but the orientation of the striae of the slickensides shows that the slip was westwards and only slightly oblique to the direction of the cross-fault. The individual veinlets are each marked by slickensides, and the striations usually give place to a fibrous or minute "rodded" structure, the fibres or rods consisting either of quartz alone or of hardened silicified mudstone. The striae on the individual veinlet surfaces are usually parallel, but they deviate sometimes by a few degrees on different surfaces, showing some

variation in the direction of movement along the same bedding plane at different times. In section the veinlets usually appear crumpled or puckered, and this crumpling into shallow folds, trending at right-angles to the striations, is often strongly marked on the surface of the vein. In places the composite vein as a whole becomes sharply folded, overfolded and thrust, and the adjacent mudstone from the bed beneath may be pinched up into the folds of the vein. (See Text-fig. 2.)

In the low cliff below the castle at Aberystwyth various joint, fault, cleavage, and other structures are displayed, which make this exposure an instructive structural "model". On the roadside a particularly interesting association of structures occurs. Here several thin bands of grit alternate with mudstones and the bedding is nearly horizontal. The grits exhibit perpendicular jointing, but the mudstones are banded, slightly warped, and show fracture-cleavage making angles up to 45° with the bedding. Close to the base of one thin band of mudstone occurs a vein of quartz about one-fifth of an inch in thickness. This vein cuts across the fracture-cleavage and appears to be of later origin than that structure, although there is no obvious infiltration of silica from the vein along the cleavage-planes.[1] Minor folding of the vein occurs, tending in places to pass into overfolding and thrusting, and must have been produced by differential movement between the layers of rock which bound the vein above and below (see Text-fig. 1). The vein is demonstrably earlier in date than an apparently reversed fault of moderate displacement which occurs a few feet to the north, for in this the vein has become involved as contorted and disrupted shreds.

The Displacement of Transverse Veins by Bedding-Faults

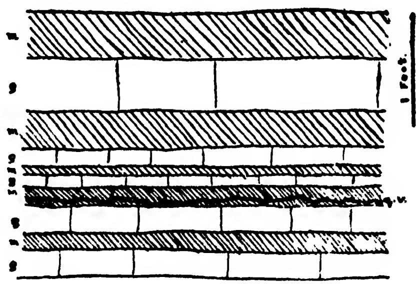
Apart from the slickensides, the most obvious and trustworthy evidence of bedding-slip is afforded by the fracture and displacement of veins of quartz which cut transversely across the bedding. The thickness of the veins affected varies from a small fraction of an inch to more than a foot, but while the thinner veins often maintain a fairly uniform thickness for several yards of outcrop, the wider veins usually show considerable changes of thickness and frequently split up into composite veins interleaved with country-rock. The slipping is usually repeated at successive

[1] According to Leith differential movement between beds (usually as an accompaniment of folding) develops one set of shearing planes parallel to the bedding and another at an angle, more nearly parallel to the axial plane of the fold. The fracture-cleavage follows this latter plane of no distortion while the other plane of no distortion is likely to be parallel to the bedding and, in incompetent beds, any break along it may escape detection. Swanson (1927) and Lovering (1928), it is true, have considered some of the theoretical aspects of fracture-cleavage as produced by rotational compression, but assuming Leith's suggestion of shearing-planes parallel to the bedding to have developed during the production of fracture-cleavage to be correct, these planes would constitute planes of weakness in the incompetent mudstones along which infiltration of siliceous or other vein minerals might subsequently take place in solution and, in some cases, they would tend to furnish planes of easier movement parallel to the bedding.

It is of interest to note that Lyell (1871) published an illustration, contributed by T. McKenny Hughes, showing the deflection of the fracture-cleavage produced by differential movements between beds in the rocks of Cardiganshire.

bedding-planes, so that, although the displacement along an individual plane may be quite small, the total displacement may be considerable. Two examples from the cliff section south of Borth may be cited in illustration of repeated slipping.

At the first locality, in the low cliff at Borth, the measures are mainly grey-blue mudstones with the paler bands about a half-inch thick forming a pattern. The cleavage approximates to the dip of the bedding, which is about 30° E., 38° S. A vein of quartz which rarely exceeds a half-inch in thickness, cuts the beds with a dip of 26° W., 15° N. Traced up the cliff from the shingle of the beach (that is, from a point about six feet north of a conspicuous fault, marked by much quartz, beyond which the beds to the south are much distorted), the vein undergoes the following apparent displacements down the dip, where " v " represents the length of the outcrop of the vein between the successive slip-surfaces, and " s " the slip or displacement of the vein, both measurements being given in inches: v 20, s 26; v 11, s 3½; v 8, s 3; v 10, s 3; v 13½, s 2½; v 9½,



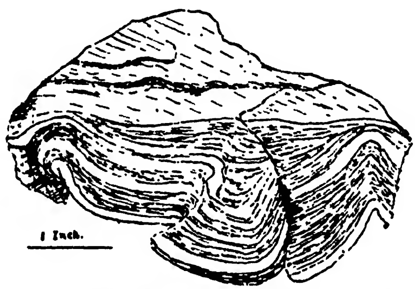
TEXT-FIG. 1.—Section in cliff-face south-west of the Castle, Aberystwyth, showing crumpling of a quartz vein (q.v.) by differential slipping of layers of mudstone parallel to the bedding. The vein cuts across the fracture-cleavage of the slaty mudstone (m). The thin grits (g) exhibit jointing which is perpendicular to the bedding.

s 3½; v 21, s 5; v 26, s 10; v 26, s 3½; v 12, s 3½; v 14, s 4; v 30, s 3½; v 36, s 5. Thus, as the slip appears to be in each case down-dip, the vein, when traced along its outcrop of 19 ft. 9 in. in the section, suffers an apparent total displacement of 6 ft. 4 in. Near by, both north and south of the large fault mentioned earlier, the displacement of other thin veins provides evidence of fairly general bedding-slip similar in character and usually in direction to that described.

A second and more striking instance of vein displacement occurs about half a mile south of Borth in a low cliff immediately south of the mouth of the small stream which flows near Pen-y-graig. At this point the beds dip at 40° S.E., and a vein, varying in thickness from 1½ in. to a maximum, as a composite vein, of 18 in., is repeatedly broken and displaced by bedding-slips. At the top of the cliff the vein is about 3 in. thick and somewhat contorted by hill-drag, etc. Traced downwards, it dips fairly constantly at 55° W.N.W. and its outcrop shows the following slips, all

apparently in one direction down the dip : s 15, v 20 (4 in. wide) ; s 18, v 25 (2½ in.) ; s 6, v 54 (4-in. vein-splits) ; s 24, v 36 (1½ in) ; (cross-fault, vein 4 in. wide, and exposed for a length of 12 ft. along the fault-crop) ; s 55, v 11 (3 in) ; s 3, v 12, with minor slips (3 in.) ; s 72, v 60 (3 in.) ; s 22, v 36 (6 in., composite) ; s 33, v 72 (18 in., composite, but 6 in. of quartz) ; shore-level. Thus the total apparent slip in the length of outcrop of about 27 ft. of the vein, ignoring the portion involved in the cross-fault, is 20 ft. 8 in. When the foreshore near the foot of the cliff is fairly free from boulders, the vein and its displacements can be followed in plan, the separated portions of the vein now occurring as strike-sections making a small angle with the strike of the mudstones and cropping out *en echelon* when followed seaward.

It is clear that in this instance the cross-faulting must have taken place after the quartz-vein was formed, for the latter was displaced and deflected by this fault.[1] The fault, also, seems to be later than the bedding-slips,



TEXT-FIG. 2.—Sketch of a specimen of a composite quartz vein resembling quartz schist, slickensided, and, in places, crumpled and gnarled by differential movements parallel to the bedding. The general direction of the striae of the slickensides on the upper surface of the vein is indicated. Cliff near Borth.

because the displacement of the vein by these movements is constant in direction on both sides of the fault. The slipping of the beds can, moreover, be assumed to be an accompaniment of the general folding of the region, and therefore the latter, in some measure, must have post-dated the veining. The folding and contortion of thick veins of quartz to be seen in neighbouring cliff sections lead one to a similar conclusion. But, on the other hand, as already stated, the veins and slipping in the mudstones, parallel to the bedding, appear in some cases to be later than the formation of the fracture-cleavage, and if this structure is dependent for its origin on the folding, the latter must in such instances pre-date the veining and the later bedding-slip. Professor O. T. Jones has already pointed out that the quartz-veins of the district are of various ages (1922, p. 180).

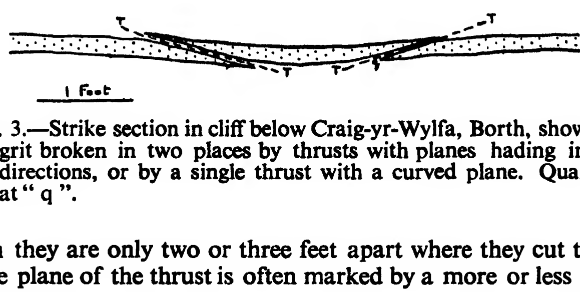
[1] A similar instance is recorded by Professor O. T. Jones from the Cwmystwyth district where he has shown that the great Ystwyth fault has caused displacement of the main galena-bearing lodes (1922, pp. 34–6, 178).

Cross-faults Displaced by Bedding-faults

Only a few examples of the cutting and displacement of cross-faults by bedding-faults have been observed in the Aberystwyth Grits, and the amount of displacement is always small. In one definite instance which is to be seen at the foot of the cliff west of Craig-yr-Wylfa near Borth (see Text-fig. 5), the plane of a normal fault with a vertical displacement of 2 inches has itself been truncated and displaced 4 inches horizontally by a bedding-fault.

Thrusts of Low Angle

In sequences composed of mudstone alternating with thin bands of grit, thrusts of low angle are to be observed not infrequently. The mudstones may then show evidence of compressive movements, as in the Craig-yr-Wylfa section to be described later. The intercalated grit bands in places have responded to the stress by fracturing along planes at an acute angle to the bedding, and the wedges of grit so produced have ploughed their way with apparent ease into the mudstones above and below. A bed of grit may show evidence of folding prior to fracture or it may not. At times there is a repetition of the thrusting in the same bed at a distance of a few feet. The planes of these thrusts either dip in the same direction (see Text-fig. 4), or in opposite directions (see Text-fig. 3),

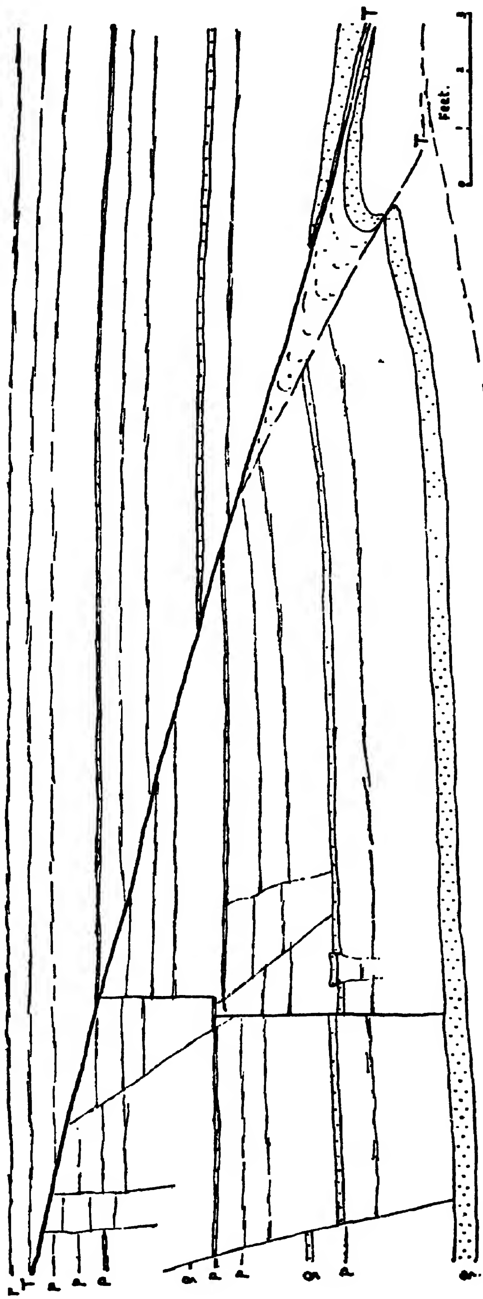


Text-fig. 3.—Strike section in cliff below Craig-yr-Wylfa, Borth, showing a thin grit broken in two places by thrusts with planes hading in opposite directions, or by a single thrust with a curved plane. Quartz-veining at " q ".

although they are only two or three feet apart where they cut the bed of grit. The plane of the thrust is often marked by a more or less persistent vein of quartz.

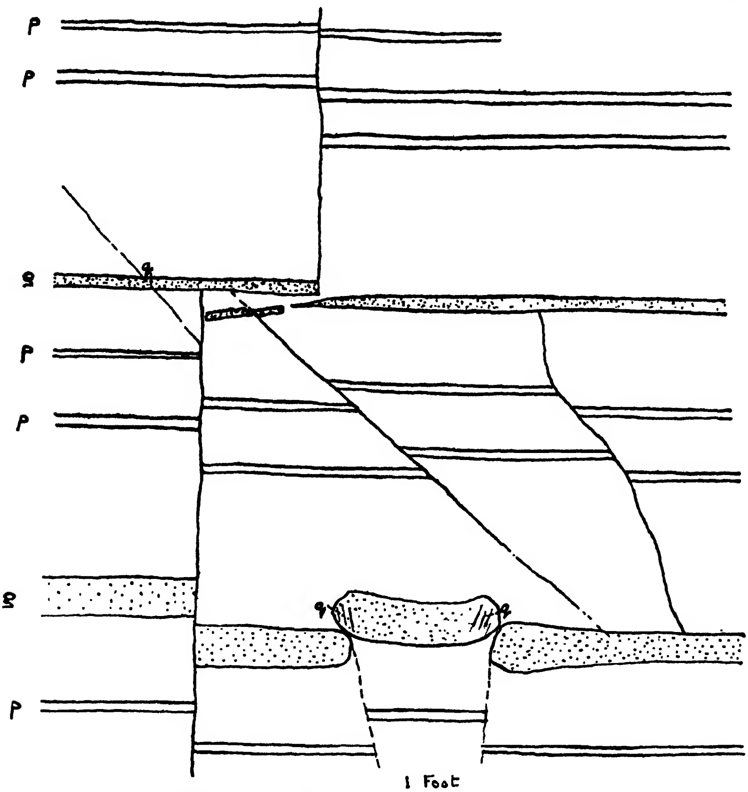
A strike section [1] in measures dipping E.S.E. at about 40°, at the foot of Craig-yr-Wylfa, but usually obscured by shingle, exhibits in miniature the relationship to one another of the structural effects produced by the compressional movements in beds of differing competence (see Text-figs. 4 and 5). At the southern end of the section a reversed fault of low angle is

[1] In this section the beds are of true Aberystwyth Grit type in lithology. They appear to form the lower limb of a syncline, over which the vertical or overturned beds of the upper limb have been driven forward by an eastward dipping thrust, so that, at this point, they are exposed higher up the cliff face. These latter beds are not the typical beds of the Aberystwyth Grit Group, but contain few and very thin seams of grit and the mudstone is usually patterned with many pale layers. Nodules and bands of cone-in-cone material are common. It is within these beds that the bedding structures described north of Craig-yr-Wylfa have been developed, while those mentioned to the south of that locality occur in typical measures of the Aberystwyth Grit Group. Professor O. T. Jones has given an outline of the general structural features of this part of the coast (1935).



Text-fig. 4.—Strike section at foot of cliff below Craig-yr-Wylfa, Borth. Mud-stones, with thin grits (g) and pale layers (p), showing the effects of lateral compression in producing thrusting, faulting, bedding-slip, and a structure approaching fault-folding (Bruchfaltung). Main thrusts at "T".

exposed. The beds above this fault show apparent thrust northwards with a displacement of three to four feet. A band of grit, which is about 4 inches thick and crops out at the base of the cliff, is seen to have been slightly over-folded and then to have snapped at two places about a yard apart. The displacement at the more northerly break, where the overfold had preceded faulting, is very slight, while at the more southerly break, where the faulting is relatively clean-cut and acute to the bedding, two thin, sharp, wedge-like masses of grit have moved differentially for about



TEXT-FIG. 5.—Northern part of section shown in Text-fig. 4, in greater detail. Quartz-veining at points marked " q ".

three feet, and the more southerly has over-ridden the more northerly fragment. The two fractures merge northwards and upwards into a single plane of thrust cutting the banded mudstones which overlie the thin grit. For some yards north of the thrust this thin band of grit remains unbroken, but the lateral compression of the mudstones, and of two very thin layers of grit interbedded with them, has given rise to small-scale slip and " horst " structures. The slipping is manifest from the displacement of a small vertical fault for a distance of about 4 inches along the bedding.

The horst-structure has been produced in the lower of the thin layers of grit as a response to lateral pressure by fracture in two places about 5 inches apart with elevation of the intervening portion into a horst-like structure having a slight synclinal sag. At the points of fracture thickening of the grit has occurred and minute parallel veins of quartz, nearly normal to the bedding, have formed in the grit as a consequence of the relief of stress.

Immediately below the main thrust and extending north of the structures just referred to, a number of small step-faults are conspicuous. Some of these seem to have been formed before the main compressive movements, for, as already noticed, one such fault has been displaced by the slipping of the bedding. It is a curious fact that while in one case the compression has resulted in bedding-slip and the driving of the ends of the thin layer of grit into the softer mudstone opposed to them, in the other, although apparently the conditions were very similar, the response to compression was by fracture of the grit itself, and the production of a horst-like structure (cf. bruchfaltung).

There is, therefore, in the Aberystwyth Grits, direct and conclusive evidence of bedding movements of a tectonic nature, the minor structures produced by them not being the result of slumping and sliding of the unconsolidated sediments at or near the time of their deposition on the sea-bed, but having their origin at much later dates, post-dating earlier veining and accompanying the regional folding in some cases, but post-dating the fracture-cleavage and later veining in others.

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Two Contrasted Types of Alluvial Deposit: with an Illustration from the Rheidol Valley, Cardiganshire

By John Challinor

(PLATE X)

In the lower parts of its course a river deposits material derived from the upper parts, this deposition being due to loss of velocity. As a deduction it seems to follow that this alluvial deposit (using the term "alluvial" in a rather wide sense) should occur as two strongly contrasted types as regards size of particles.

In the first place there is the material deposited in the bed of the stream. At any one place along the course the particles of this material will be those that, by reason chiefly of their size and shape, have travelled just as far downstream as they can when the river has been swiftest at the time of greatest flood. The particles of the main mass thus deposited may be stones forming a coarse shingle even in parts of the valley, not far from the sea, where the river has a very low gradient and is meandering conspicuously.

In the second place there is the material deposited on the flood-plain from nearly still water, but again when the river is flooded. This material will be composed of very fine particles; will, in fact, be chiefly mud.

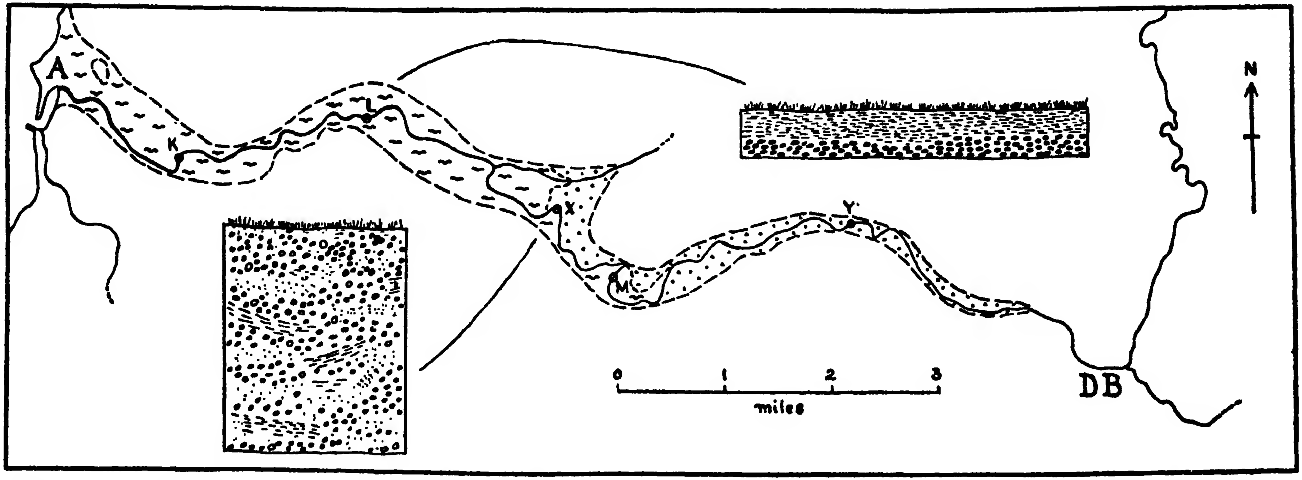
As the river changes its course in the process of meandering it spreads a widening layer of shingle along the gently shelving banks on the convex sides of the curves of the stream-bed, while over the flood-plain as a whole it deposits a layer of mud which is held and bound by vegetation.

Where the river is approaching base-level the rate of down-cutting is exceedingly slow. The river may therefore be visualized as cutting only laterally. We should then expect the sections exposed in the approximately vertical banks of the concave sides of the curves of the stream-bed to show the first type of deposit (stones) below, separated sharply from the second type (mud) above.

The actual conditions however are not very rigid. When the river is swollen and overflows its banks there is a swift current over a wider belt than that defined by the normal stream. Cut-offs and deserted channels are filled with parts of the flowing river and new channels are liable to be initiated. Such things as these will introduce complications into the conception outlined above which is too simple to fit the natural conditions in detail; but nevertheless it is probably true to say that, in a general way, when the river is in flood these two contrasted types of deposit are likely to be laid down on the alluvial plain.

It is necessary that the river should have access to rock-material of all sizes and this will normally be available when the river is flowing over a region of hard rock, at least in the upper parts of its course. It will also be available—and here the conditions will be especially favourable—when the river is eroding glacial material composed of rock particles of all sizes.

These latter conditions are realized in the valley of the river Rheidol, Cardiganshire (see Text-fig. 1). The river emerges from a platform or terrace composed of stones, sand, and mud (from coarse bouldery deposits



TEXT-FIG. 1.—The figure is a sketch-map of the greater part of the Rheidol Valley, Cardiganshire, the course of the river being based on the 1 in. Ordnance Survey map, with some emendations to bring the meanders into their present positions. The river rises in the mountain region of Plynlimon some six miles (in a straight line) north-east of the point where it enters the map. The limits of the valley-floor are shown by broken lines, the platform of glacial material being indicated by dots and the alluvial deposits by the flying-bird sign. Where the two are adjacent, the boundary between them is either the river itself or is shown by a line of small dashes. On conveniently unoccupied parts of the map are shown two diagrammatic sketch-sections. The one to the south-west is of part of the river-bank cut in the platform, as at X or Y on the river's course. Such sections are commonly some 20 feet high. That to the north-east is of part of the river-bank cut in the alluvial deposits, as at K, L, or M on the river's course. Such sections are commonly some 4 feet high. A is the town of Aberystwyth, DB the village of Devil's Bridge.

to the finest laminated clays) mixed up in the greatest confusion, and then proceeds to sort out the stones and the mud and to lay them down separately on the flood-plain with remarkable neatness. This may be strikingly seen in nearly every section of the alluvial deposits cut along the banks on the concave sides of the meandering curves of the river channel. Much of the material eroded by the river from the glacial (or fluvio-glacial) platform and elsewhere is, of course, carried beyond its mouth, as is very obvious by the discoloration of a broad belt of the sea after every rainstorm.

The writer has so far failed to find, amongst the literature dealing with the action of rivers, any reference to a principle whereby the tendency towards the production of these two kinds of deposit is inevitable. He has not been able to make a thoroughly systematic search for descriptions of actual sections as this would involve going through many local reports and records which are not available to him; but in the more readily accessible literature such descriptions appear to be few and meagre [1] and where there are any it seems to be generally assumed that vertical variation in character denotes corresponding variation (in the course of time) in gradient, climate, source of material or some other external factor. However, it is here suggested that the two contrasted types of deposit may be laid down, one on the other, as a natural result of a river working under constant general conditions. Any particular succession of deposits in, for instance, a river bank, or in excavations or borings, should be interpreted on its merits, bearing all the possibilities in mind.

In other North Cardiganshire rivers there are frequent examples of the same kind of thing as is to be seen along the banks of the Rheidol and if observations were to be made in other parts of the country these might go to show how far the principle is confirmed by facts from beyond the bounds of one particular district.

Finally, the writer should make it clear that he is not claiming to have discovered a succession of river deposits that has not been noticed before. The more previously-recorded instances of this twofold succession that may come to light the better for his argument. It is the principle, though a simple one, that he has never seen discussed and as it appears that, if sound, it may be of some little importance he ventures to suggest that students of river-action might give it their consideration.

EXPLANATION OF THE PLATE

The upper photograph shows the glacial, or fluvio-glacial, deposits in the right bank of the river at the point marked X on the map (Text-fig. 1). Taking the section as a whole, stones and particles of all sizes are mixed together though there is a certain amount of bedding. The lower photograph shows the two contrasted types of alluvial deposit in the left bank of the river at the point marked L on the map. The partly dried and solidified mud of the upper layer is emphasized in the view by the nesting-holes of sand-martins.

[1] The writer is indebted to Mr. A. S. Kennard for kindly drawing his attention to those in Whitaker's Geology of London (*Mem. Geol. Surv.*, 1889), in Spurrell's paper in the *Proceedings of the Geologists' Association* (1889) and in several papers in the *Essex Naturalist* about the turn of the century.

DEPOSITS EXPOSED IN BANKS OF THE RIVER RHEIDOL.

The Lamprophyre Problem

By H. G. Smith, Queen Mary College

JUDD was one of the early workers to recognize that changes in the mineral constitution of an intrusive igneous rock, changes affecting the earlier minerals, may take place prior to the completion of crystallization. He points out that minerals, since their first crystallization, may have undergone several series of changes, totally dissimilar in kind, and resulting from causes altogether different, and that the dissolved material may be carried away from a crystal and deposited within the cavities of neighbouring crystals of different species. This process must result in the blending together in the most inextricable manner of material derived from different crystallized minerals, and the whole characters of the rock may be completely altered.

Sollas developed the idea in pointing out that the biotite in many granites seems scarcely to have completed its growth before its destruction commenced, and simultaneously muscovite came into existence, building up its crystals about the fretted fragments of dissolving biotite. The mica already formed was attacked and partly destroyed by the free silica of the magma, its dissociated molecules entering into new combinations, contributing to, if indeed they did not initiate, the formation of felspar.

Holland also points out that the use of the term secondary when applied to rock alteration is but relative. The minerals of early consolidation may be attacked and altered soon after their formation by the vapours originally included in the magma and excluded to the mother liquor, or they may become attacked at a distinct and subsequent period. In the former case the processes of primary crystallization and secondary alteration are in reality phases of the same process. The consolidation of the rock and its alteration were continuous.

Bowen, in tracing the history of differentiation, contends that the increased concentration of water exerts a strong influence in promoting the breakdown of the polysilicate molecules of the alkalies and the metasilicates of iron and magnesia into the orthosilicate molecules with setting free of silica. Such changes are effected during the course of crystallization, but he also cites evidence to show that a hornblendic rock without quartz may, even after complete solidification, be changed to a biotite-quartz rock during metamorphism, when there is special activity of volatile constituents. It should be noted that this post-solidification change was visualized by Holland, as noted in the preceding paragraph.

Again, Sederholm contends that coronites have originated, not merely by reaction between adjacent minerals, which have supplied only a part of the constituents of the coronas; another part has been transported in solution from more distant places of the same rock masses. Kemp and Marsters consider dykes, wherever found, as the offshoots or apophyses of larger igneous masses. Even though these larger masses may not be visible, the authors claim that it is reasonable to conceive of some such body below the surface. Spurr supports this view, claiming

that portions at least, if not all, of the solid crust of the earth are underlain by fluid and uncrystallized rock magmas. Flett, dealing with the dykes of Caithness, considers that their wide distribution and the uniformity of their trend would lead us to believe that they belong to an epoch when a considerable area of the north-east of Scotland was underlain by a basic magma. Shannon puts forward a similar view when he says that the presence of lamprophyric rocks in wide distribution over the region constitutes the strongest argument in support of the assumption that the region is underlain by a granitic batholith. Barrell agrees that the evidence of exposed regions suggests that Tertiary granite should occur widely in depth under much of the Cordilleran province. Grout also calls attention to the probability that batholiths may spread widely under the crust without exposures, and additions or metasomatic changes may be widespread around them.

That the intrusion of lamprophyres comes late in the history of the area is indicated by Clough when he points out that these dykes do not keep to the bedding or foliation of the schists, but may be seen constantly cutting across all their crumplings; all the movements responsible for the foliation had ceased before the intrusion. In the memoir on Oban and Dalmally it is mentioned that the camptonites and monchiquites cut the later and more acid phase of the granite, and that it is probable that they represent basic modifications of the underlying magma intruded during the later portion of the dyke-forming period. The mica traps of Dartmoor are not sheared, but form small ramifying dykes following joint planes, which developed after the shearing of the Palaeozoic rocks. Lindgren and Bastin also state that the lamprophyre appears to be the youngest rock of the district and is entirely unmineralized. Bowen, studying the Fen area of Norway, says that the lamprophyre dykes from the intrusive are frequently found to be later than the replacement.

Inclusions in the lamprophyre are recorded by Clough, those of hardened schist and vein quartz reaching a length of four inches; in some bands the inclusions make up a quarter of the rock mass. A similar case is recorded in the Oban and Dalmally memoir, the weathered face being thickly studded with quartzite fragments, and in places the rock is so full of these fragments as to resemble a breccia. In the Ben Nevis and Glencoe memoir there is a suggestion that a fault intrusion incorporated fragments which were the result of brecciation, the fault plane being stripped clean and bare. Read records abundant inclusions of different kinds of rock, often spherical or ellipsoidal, and claims that there is no visible endomorphic effect in the lamprophyre at the junctions.

Flett records similar inclusions, most of them the size of a walnut or less.

Adjustments following on the crystallization of part of the contents of a batholithic chamber would account for faulting in the rocks above it, and if this faulting was accompanied by brecciation, the late, lamprophyric magma might be expected to find such bands of crushed rock to be suitable avenues for their uprise. Such sagging in the roof of a batholithic chamber is deduced by Spurr, and also in the case of the cauldron subsidence of Glencoe.

That later dyke intrusions follow channels already occupied by an

earlier one has been adequately demonstrated by Harker. He describes an acid magma following on a more basic one, and leaving only much-corroded relics of the basic rock. Thus, in addition to brecciation, we have another possible explanation of the heterogeneous character of certain intrusive rocks. But this coincidence of path applies not only to magmas but to gaseous constituents also. In the Oban and Dalmally memoir it is recorded that several of the fissures occupied by composite dykes have been used as an escape for gases, after they had been filled by one or more of the earlier molten intrusions, as they are partly filled with agglomerate and tuff, made up of small fragments of these rocks as well as of the walls of the fissures ; the explosion has disrupted the dykes, the broken ends of several of which are seen on each side of the vent. Similar blow-holes along the course of Tertiary dykes are recorded in the Mull memoir.

It would appear, however, legitimate to entertain the view that such emergence with violence is the exception rather than the rule. There must be numerous examples of slow uprise of gases within the substance of the dyke, and ample opportunity for reactions between them and the constituent minerals. If it be admitted that the rising gases tend to follow by preference the fissure already occupied by the dyke, obviously not permanently sealed at its lower end, it is not a matter for surprise that mineral changes take place ; it would be a remarkable fact if they did not. A dyke would appear to supply ideal conditions for mineral re-arrangements. The assumption that all the minerals now forming the dyke result from orthomagmatic processes is certainly unjustified.

The possibility of the formation of new minerals as a consequence of such permeation is indicated by Sollas when he calls attention to the existence of basaltic brown hornblende, evenly scattered through parts of a granophyre, which might easily be taken for original constituents. Eskola also insists that the order of idiomorphism is not necessarily identical with the order of crystallization. Barrell regards the fluids and gases of igneous rocks as of juvenile origin, making their way for the first time toward the surface of the earth ; and he stresses the important fact that emanations from the same magma at different stages are of highly different character. Another point he makes is that in so far as the water as gas or liquid is under great pressure, it will tend to enter into the form of hydrates, since the hydrated minerals in general occupy less volume than the equivalent anhydrous minerals plus the water in uncombined form ; hydration may thus take place at relatively high temperatures. Many replacements are attributed by Schaller to the action of ascending solutions, other felspars being replaced by albite ; even quartz suffers in a similar way. Further replacements also take place, resulting in the formation of garnet and tourmaline. About the same time Hess, also working on pegmatites, came to very similar conclusions. He regards albite as the universal devourer, although it is itself eaten by others. The replacement is not confined to the dyke, the country rock also suffering to some extent, but the path followed by the pegmatite, even after freezing, is often also the path of least resistance for the fluid. He considers that quartz is held in solution at temperatures lower than those at which other minerals are precipitated, and therefore

quartz is carried farthest, forming quartz veins as upward prolongations of the pegmatite. He considers that continued flow of solutions supplies the only possible explanation for the observed facts. Landes, also studying pegmatites, points out that a slight difference in the character of the ascending solutions would cause an earlier mineral to become unstable and a new one to be deposited. Sederholm emphasizes the necessity of solvents in metamorphic changes, and says that these are, in general, exudations from eruptive masses, either visible or hidden at great depth.

Larsen, opposing the theory of desilication as applied to corundum-bearing pegmatites, suggests that the alumina was deposited from ascending solutions moving along the borders of the pegmatite, effecting deposition in the vein and also in the country rock. It will be noticed that the solutions are considered to have come, not from the visible igneous rock, but to have originated at greater depth. Fenner considers that thermal waters have the effect of separating quartz even from very basic rocks, and that some of the quartz of late crystallization in basic rocks, attributed to orthomagmatic processes, may, in fact, be a hydrothermal product. He stresses again that pneumatolysis or a high grade of thermal metamorphism frequently produces the same or very similar assemblages of minerals as orthomagmatic crystallization. He deplores the fact that idiomorphism is still regarded by some workers as evidence of early crystallization, even though many examples of the growth of these metacrysts have been described. It is necessary to repeat that well-formed crystals may have had their origin at a late stage in the magmatic history of the rock. Fenner claims that this is especially clear with hornblende and biotite. There is good reason to suppose that the gases given off from the differentiating magma in the chamber below include water, carbon dioxide, potash, soda, phosphorus, sulphur, and fluorine ; and that the relative amounts of these vary as the process continues.

By Grenville Cole, garnets are pictured as arising during the early stages of metamorphism of the invaded masses, and then being carried off, and frequently dissolved, by the ascending magma, which, in the first instance, was responsible for their growth. Sederholm regards garnets as a product of the crystallization of an acid, residual magma, abundance of solvents being an essential condition. He also mentions the occurrence of garnets in such basic rocks as have been influenced by granitic ichor ; that is, where acid and basic material have come into contact.

Suggested conditions for the manufacture and emplacement of lamprophyres may now be permissible. Daly, working on the hypothesis of primary basaltic magma, visualizes this as occupying a magma chamber, and freezing where it is in contact with the country rocks, including the roof. The interior of this chamber, occupied by the still liquid magma, became the location of some kind of differentiation, which caused the accumulation in its upper layers of the lighter, residual magma. As this gravitation effect continued, the upper liquid layers became more and more contrasted with the solidified basalt under which it lay. In accordance with the principles laid down in Bowen's reaction series, the minerals of the basalt were made over into those later in the series, but it is conceivable that olivine, the highest temperature mineral, would still retain its individuality in some cases. The constituents of the roof basalt,

however, may have been completely re-sorted, and then the overlying, earlier rocks, whatever their nature, would in their turn be attacked. Meantime, these cover rocks, deprived of support by progressive crystallization and contraction in the chamber below, may be expected to subside, no doubt differentially ; faults may be expected, and these would provide easy avenues of escape for the magma below. Thus, late in the crystallization history of the chamber, there may be expected uprise of residual magma which has to some extent suffered admixture and reaction with the overlying basalt. If we accept the opinion of Sederholm with regard to the tendency to form garnets where acid and basic meet, there has been ample opportunity.

Another possible factor enters. There is every reason to suppose that the base of the cover rocks was extremely irregular, and there would thus be upward protrusions of solidified basalt ; and if, as is probable, the accumulating gases ascend there most easily, the upreaching fingers would acquire mobility because of the heat supplied by the gases, and also by their mere presence. And, as pointed out by Smyth, quite apart from the weakness of the cover induced by faulting, this cover may have been tight enough to resist the gas pressures in the early stages of differentiation but may be permeable at the higher pressures resulting from concentration of volatile constituents with progressive differentiation. Reactions between acid and basic magmas, and also of each with the gaseous constituents, may be expected both in the upper part of the magma chamber and in the dykes which are the upward extensions of it. The inclusions consisting largely of corundum and green spinel, recorded by Flett and also by others, may find their explanation in the disintegration of almandine, the gaseous constituents causing release of silica from its combinations. Similarly, the known occurrences of sillimanite and kyanite may have been produced as a consequence of the breakdown of alkali felspar.

The spherulitic shapes, standing out in relief on weathered surfaces, recorded by Clough and later by others, largest in the centre of the dyke and becoming progressively smaller as the margins are approached, are probably attempts at the formation of crystals of analcite. Clough also calls attention to the special occurrence of amygdules in the centre of the dyke. Both these facts may find their explanation in the rise of volatiles at a time when the margins were frozen while the centre was still liquid. The radiate and fan-like grouping of relatively acid felspars, attributed by Harker to acidification of basic rocks, finds a ready explanation if the exchanges here postulated are admitted. The frequent parallelism of the biotite crystals may be due to movement during crystallization or to the operation of the so-called Riecke's law, the deposit of new mica on the edges of the crystal where the pressure is least, as suggested in the Ben Wyvis memoir.

If we assume that the early gases were rich in potash, and that they later became richer in soda, we find some sort of explanation for first the building of biotite, and later its corrosion, as indicated by its embayed margins. The occurrence of soda pyroxenes and amphiboles, well displayed in some Jersey examples, and probably of late origin, has some bearing on the question.

It is perhaps necessary to state, as Spurr does repeatedly, that associated igneous rocks do not of necessity belong to the same cycle; dykes, upward extensions from a batholith, may penetrate intrusive rocks of much earlier date.

In addition to the work already assigned to them, the volatiles, in this case carbon dioxide, are called in to account for the ubiquitous calcite. This, of magmatic origin, acquired its calcium from the lime felspars, and carried it up to higher levels.

It is freely admitted that a considerable part of this contribution is based on opinion, and that proof is wanting, but the conviction is here expressed that the deadlock reached with regard to these troublesome rocks is due to rigid belief in orthomagmatic crystallization. Minerals do not all remain in the condition in which they first crystallized, and volatile constituents do exist. No doubt it is a mistake to confer omnipotence on the volatiles, but to ignore them is to be guilty of a colossal blunder.

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ANNOUNCEMENT

THE ROYAL ASTRONOMICAL SOCIETY

The Council of the Royal Astronomical Society announce that Geophysical Discussions have now been resumed. These are open to non-Fellows and are held in the Society's rooms at Burlington House, Piccadilly, London, W. 1, at 16 h. 30 m. on the third Friday of the month.

During 1946–7 it is hoped that there will be six Discussions, in October, November, January, February, March, and May.

Some or all of the following subjects will be discussed :—

The Burton-on-Trent Explosion
English Oil Fields
Modern Methods of Time-Keeping
Geochemistry
Atmospheric Oscillations
Geophysical papers submitted to the Society

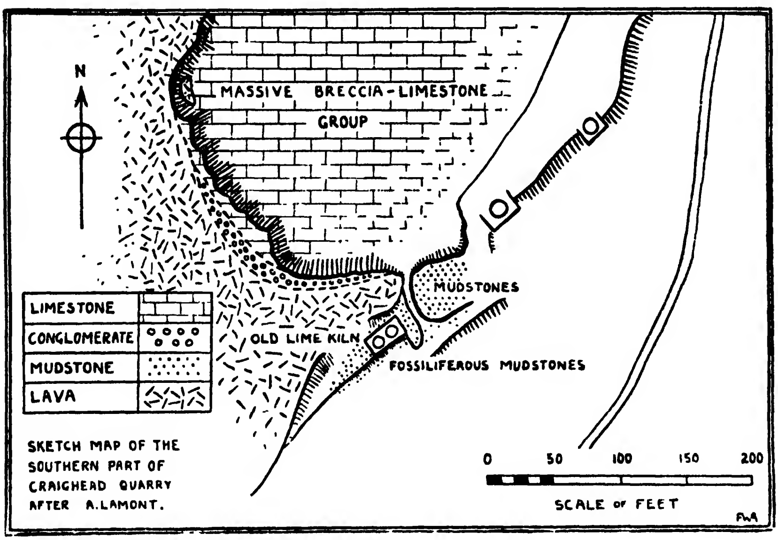
Announcements, giving further details, will normally be found in *Nature*, published nine days before each discussion.

On a Section of the Balclatchie Beds at Craighead Quarry, near Girvan, Ayrshire [1]

By F. W. Anderson and J. Pringle

In recent years the stratigraphical position of the Craighead Limestone, as assigned by Lapworth (1882) and by Peach and Horne (1899), has been questioned by such competent geologists as Ulrich (1930), O. T. Jones (1935), and Cowper Reed (1935); any new evidence having a bearing on the age of the limestone is therefore worthy of being placed on record.

The object of this paper is to describe a section which has been recently exposed below the old kiln at Craighead quarry (Text-fig. 1), and to refer briefly to fresh information brought to light by the extension of the quarry since 1935.



(a) The Old Lime-kiln Section

As shown in Text-fig. 1 a new (in 1938) section has been temporarily exposed in the embankment below the disused lime-kiln at the south-western corner of the quarry. The rocks consist of fossiliferous, olive-green sandy mudstones dipping steeply to the south-east. They contain hard calcareous bands and nodules and are closely jointed and shattered.

[1] Communicated by permission of the Director of the Geological Survey of Great Britain.

These beds pass laterally into the argillaceous sediments exposed in the narrow cutting leading into the quarry, but though of similar lithology the latter appear to be unfossiliferous except at the southern end of the cutting where fragments of shells can be seen.

It is not our intention here to discuss at any length the field relations of the Craighead Limestone Series, in view of the forthcoming Geological Survey Memoir on this district (1 inch Sheet 14) where such questions can be adequately dealt with. It is perhaps sufficient to say that in our opinion the succession as determined by Lamont (1933) and shown on the map accompanying his paper appears to be in accordance with the facts. According to that author the mudstones described by us lie below the breccia-limestone group of the main quarry. Further, a thin brecciated band of similar lithology overlies the shaly-limestone group on the east side of the quarry. Still older beds are exposed in a small disused quarry 200 yards south-west of Craighead quarry in which breccia-limestone is to be seen resting against steeply inclined pillow-lavas and overlain by a thin series of shaly-limestones. These in turn are overlain by mudstones very like those at the entrance to the main quarry.

It appears therefore that these mudstones occur as intercalations in the Craighead Limestone Series and that the age of the mudstone fauna must necessarily determine the age of the Craighead Limestone itself.

Recognizing the stratigraphical importance of these newly exposed fossiliferous mudstones the writers, who first noticed them, made a collection of fossils from the section below the kiln, and the collection was added to on subsequent visits with the assistance of Dr. J. E. Richey and Mr. R. Eckford. The fauna is large and varied, containing sponge remains, crinoid stems, an echinoid plate, corals, bryozoa, brachiopods, lamellibranchs, gasteropods, ostracods, and trilobites.[1]

Of these the following species have been determined :—

Lingula amabilis Reed.
Leptaena rhomboidalis (Wilckens), variety.
Orthis ("*Plectorthis*") *ardmillanensis* Reed.
Orthis (*Ptychopleurella*) *balclatchiensis* Davidson.
Orthis ("*Plectorthis*") *duftonensis* Reed, variety.
Orthis playfairi Reed.
Paterula balclatchiensis (Davidson).
Rafinesquina (*Playfairia*) *deltoidea* (Conrad) var. *multicorrugata* Reed.
Sowerbyella sericea (J. de C. Sowerby), and variety.
Ambonychia amygdalina Hall.
Ctenodonta eastnori (J. de C. Sowerby).
Modiolopsis subquadratus Hind.
Nuculana imbricata (Portlock).
Vanuxemia distans Hind.
Streptelasma craigensis M'Coy.
? *Acidaspis* sp.
Cryptolithus sp.

[1] The trilobites were named by Dr. C. J. Stubblefield to whom the authors are greatly indebted.

Cybele cf. *bellatula* (Dalman).
Encrinurus cf. *multisegmentatus* (Portlock), [pygidium].
Encrinurus sp. *multisegmentatus* group [glabella].
Illaenus balclatchiensis Reed.
Lichas cf. *hibernicus* (Portlock).
Phacops sp. nov.

The majority of the fossils listed above are only found in the Craighead Limestone and Balclatchie mudstones and the occurrence of several species, such as *Rafinesquina* (*Playfairia*) *deltoidea*, var. *multicorrugata* and other brachiopods which are restricted to the Balclatchie beds leaves no doubt that the mudstones now described belong to that subdivision.

Peach and Horne reported the presence of " greyish-yellow shales in which Professor Lapworth identified casts of the genera *Encrinurus*, *Ampyx*, *Trinucleus*, *Leptaena*, *Strophomena*, *Orthis*, and *Cythere* " overlying the graptolitic shales exposed on the east side of the quarry. Unfortunately no trace of this exposure now remains, but there seems little reason to doubt that these were mudstones similar to those described above and occupying a higher horizon in the Craighead Limestones Series.

(*b*) The Extension of Craighead Quarry [1]

The work at Craighead during recent years has extended the quarry northwards until it has now reached the road. On the map published by Lamont (1933) the breccia-limestone group of the main quarry was shown passing northwards into a higher shaly-limestone group. The writers visited Craighead in 1937 with the intention of examining any still higher beds which had been exposed by the extension of the quarry in that direction. It was found that the shaly-limestone group was succeeded by massive beds of the breccia-limestone type, which were also seen outcropping in the burn north of the road. The remains of old quarrying operations in the wood beyond (Muiryett Plantation), round which are strewn numerous angular fragments of limestone, indicate the site of the old East Quarry of Lapworth. The writers are therefore led to agree with the opinion expressed by Bailey (1928) that the Craighead Limestone Series extends beyond the present quarry into Muiryett Plantation and probably underlies the graptolitic shales and flagstones exposed in the burn 200 yards east of Redgate. From these shales Mr. Eckford obtained the following graptolites: *Climacograptus antiquatus* Lapworth, *C. lineatus* Elles & Wood, and *Amplexograptus perexcavatus* Lapworth; a fauna assigned by Dr. Elles, who examined the specimens, to a horizon near the base of the *Climacograptus peltifer* Zone or at the top of the *Nemagraptus gracilis* Zone. Two of these species, however, range up into the Hartfell so that a higher horizon for these beds is not impossible.

Accordingly the revised interpretation of the succession within the Craighead Limestone Series suggested by the writers is :—

[1] The West Quarry of Lapworth.

	7. Graptolitic Flagstones.	Burn section. Muiryett Plantation.
	6. Breccia-limestone.	
	5. Shaly-limestone.	
Transgressing on to Arenig lavas.	4. Breccia-limestone.	Craighead Quarry.
	3. Mudstones.	
	2. Shaly-limestone.	Old quarry to S.W. of Craighead Quarry.
	1. Breccia-limestone.	

(*c*) Age of the Craighead Limestone

The Craighead Limestone has in the past been assigned to various positions in the stratigraphical succession from Upper Llandeilo (= Caradoc Series of the Geological Survey of England and Wales) to the lowest Silurian of America. Lapworth regarded it as being of Upper Llandeilo age because of the occurrence above it of shales containing Glenkiln graptolites, and the equivalent of the Stinchar Limestone. These shales are no longer to be seen, but from the limestone itself graptolites have been collected which include a doubtful specimen of *Climacograptus wilsoni* (Hartfell); the rest may belong to either Glenkiln or Hartfell.

Nicholson, from a study of the corals, concluded that the Craighead Limestone was of Lower Silurian (Ordovician) age corresponding with the upper part of the Trenton Limestone or the beds of the Cincinnati and Hudson River Formation of North America. On account of the trilobite fauna it was assigned to the Caradoc by R. Etheridge, junior. The Geological Survey, represented by Peach and Horne, followed Lapworth and placed it in the Upper Llandeilo (Caradoc). More recently Ulrich has suggested that the Craighead Limestone is of the same age as the Keisley and Kildare limestones, which are generally believed to be of Upper Bala age (Ashgillian), but which he would make equivalent to the Upper Richmond Formation (lowest part of the Silurian) of America. Cowper Reed, after a comprehensive study of the Craighead fauna, has come to the conclusion that it has little in common with the fauna of the Stinchar Limestone with which it has so often been correlated. Stubblefield (1939) has recently presented evidence from trilobite faunas which links the Craighead Limestone with the Balclatchie mudstones. Pringle (1935) states that the Craighead Limestone fauna clearly indicates a Caradocian age for these beds, a conclusion with which the present writers agree.

The discovery of a Balclatchie fauna in the intercalated mudstones implies that the Craighead Limestone is of Balclatchie age and is therefore younger than the Stinchar Limestone. The Craighead Limestone appears to be a reef phase in the Balclatchie Group, an interpretation which explains the general similarity of the two faunas and at the same time

accounts for the considerable difference which exists between the faunas of the Craighead and Stinchar Limestones. Further, though none of the fossils so far discovered allows of a precise placing of the Balclatchie mudstones—Craighead Limestone series in the zonal scheme, the general indication is that of a horizon at the top of the Glenkiln Shales or at the base of the Hartfell with a slight balance in favour of the former.

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A Replacement " Pegmatite " Vein in the Carn Brea Granite

By J. Stuart Webb, Beit Scientific Research Fellow, Imperial College, London

(PLATES XI AND XII)

SECONDARY silicification of country rock is commonly observed in many geological environments, and it is generally considered that this metasomatism was effected by hydrothermal siliceous solutions permeating the host rock. Silicification may be localized in comparatively narrow zones alongside the channelway used by the solutions, or it may result in a regional alteration of a large mass of rock. The former type of occurrence is commonly observed alongside veins of presumed hydrothermal origin (1, 2) whilst the latter is sometimes seen in rocks, e.g. silicified limestones (1, 3) with no evidence of a path followed by the solutions. In such cases a mechanism of sub-capillary soaking must be assumed ; the solutions may act selectively by favouring certain bands or types of rock.

This paper gives a description of a rather unusual occurrence observed in the course of an investigation of the tin lodes of Cornwall. In this case silicification is extremely well localized to form a vein-like body, but there is no evidence of a primary fissure and the occurrence thereby differs from the more common examples of silicification alongside discrete vein deposits of quartz (or other minerals) and the formation of irregular bodies by non-localized metasomatism.

Specimens were obtained from South Crofty Mine, situated near the Carn Brea granite outcrop approximately mid-way between Camborne and Redruth, Cornwall. The tin lodes at South Crofty are worked from two shafts, Robinson's and Cook's Kitchen ; the vein described on these pages outcropped in the drive connecting Robinson's and Cook's Kitchen Sections at the 290 fathom level. It is well in the granite, being probably more than 600 feet from the contact between the granite and the metamorphosed sediments (killas).

The level was driven along the No. 1 lode which is seen in the roof of the drive at this point. It is a chloritic tin lode which is later than the quartz veins. These latter are cut and sometimes slightly displaced by chloritic stringers, contemporaneous with the lode. The quartz veins, chloritic stringers, and the lode trend in the same direction, i.e. 50° E. of N., and appear to dip steeply to the south.

The country rock is a medium-coarse grained biotite-muscovite granite, predominantly grey in colour and with occasional off-white potash felspar phenocrysts. Like most underground rock surfaces the exposures are obscured by accumulations of dust and slime, making accurate measurements difficult or, as in this case where limited scaling of the roof had taken place, too localized to be of much significance. The structures (joints, etc.) of the granite will, therefore, be omitted as not essential to this discussion.

The tin-bearing lode just outcrops in the roof of the level, the footwall is not exposed. A traverse across the drive from north to south

shows the lode to pass into a zone of chloritized granite about 2 feet wide on the hanging-wall. Outside this zone the granite is traversed by numerous chloritic stringers and a smaller number of siliceous veins up to 2 or 3 inches wide. These quartz veins contain more or less felspar and in all cases are earlier than the lode and its associated veinlets.

Replacement Quartz Vein

One quartz vein showed certain interesting features particularly well and is described and illustrated here.

Plate XI is a photograph of a specimen from this vein reduced to three-sevenths. The vein is clearly seen running down the centre of the piece of granite host rock; the walls are well defined; strike and width are fairly uniform, and in places large felspar crystals stand out well in contrast to the quartz. The vein could be described as a pegmatite on its mineralogy, but in view of the origin of this body the term "(replacement) quartz vein" has been used throughout this paper. The thin dark lines traversing vein and granite at an acute angle to the former are chlorite-tourmaline veinlets, associated with the tin lode 5 feet away and striking sub-parallel to the replacement quartz vein.

The host rock is a grey granite containing both muscovite and chloritized biotite; there is some doubt as to whether any of the muscovite is an original constituent of the granite and much of it is obviously secondary as shown in a later page. The rock is medium to coarse grained —average grain size of the quartz and felspar is about $\frac{1}{4}$ inch, but the mica is conspicuously finer grained. Pale salmon-coloured felspar phenocrysts occur up to 2 inches in length, these vary from sub-hedral crystals to irregular clots. They have a rough planar arrangement cutting across the vein at an angle of $25° \pm$.

Alongside the vein the granite is seen to be darkened, due to the development of greyish brown mica and the slight silicification of the felspars. This alteration is thus a greisenization of the granite, and it becomes progressively less intense away from the vein. The zone is irregular and the modification affects the wall rock noticeably to a maximum depth of 5 inches. Greisening is in no way connected with the chlorite-tourmaline stringers cutting the vein. This is shown by the lack of alteration near the right-hand edge of the specimen (Pl. XI) which is the wall of one of these late stringers.

A separate area of silicification in the granite 2 inches from the vein is noticeable near the top edge of the photographs (Pl. XI and XII). There is little mica present here, and relics and corroded edges of the felspar indicate replacement by quartz. Original and late quartz are indistinguishable.

The quartz vein has an average width of $\frac{3}{4}$ inch (the photographed surface of the vein is not quite perpendicular to the dip). The vein quartz appears massive and is similar in appearance to that in the granite. It is, however, the mode of occurrence of the felspars in the vein which is especially interesting. Individual grains may be isolated in the quartz, but the great majority of the larger crystals project into the granite for varying distances, and a few crystals pass through the vein and project into the granite on either side. Such felspars can be seen in Pl. XI, and

QUARTZ-FELSPAR VEIN.

Note prolongation of granite felspars through the vein and the preservation of their linear orientation ; also the dark greisen zone along the vein walls and the silicified clot at " A ". The thin dark lines traversing the vein at an acute angle are later chlorite-tourmaline stringers. This photograph is $\frac{3}{4}$ natural size.

UPPER HALF OF VEIN SHOWN IN PLATE XI. THE FELSPARS HAVE BEEN OUTLINED.

Note form and general orientation of felspars in the granite also the silicified clot at " A ". This photograph is $\frac{5}{6}$ natural size.

are made clearer in Pl. XII which is an enlargement of the upper portion of the vein shown in Pl. XI. The felspars in the vein are more ragged in outline than those in the granite, and relics are common. There is a very slight difference in colour between felspars of the vein and those of the granite : the former are somewhat paler and are less stained with iron oxides. Preservation of the original alignment of the felspars in the granite is clearly shown in the vein. No evidence of displacement or of an original fissure can be seen, though very slight movement has occurred along the late chlorite-tourmaline veinlets. Broadly speaking the felspar distribution-pattern in the vein bears a perfect resemblance to that of the same mineral in the granite.

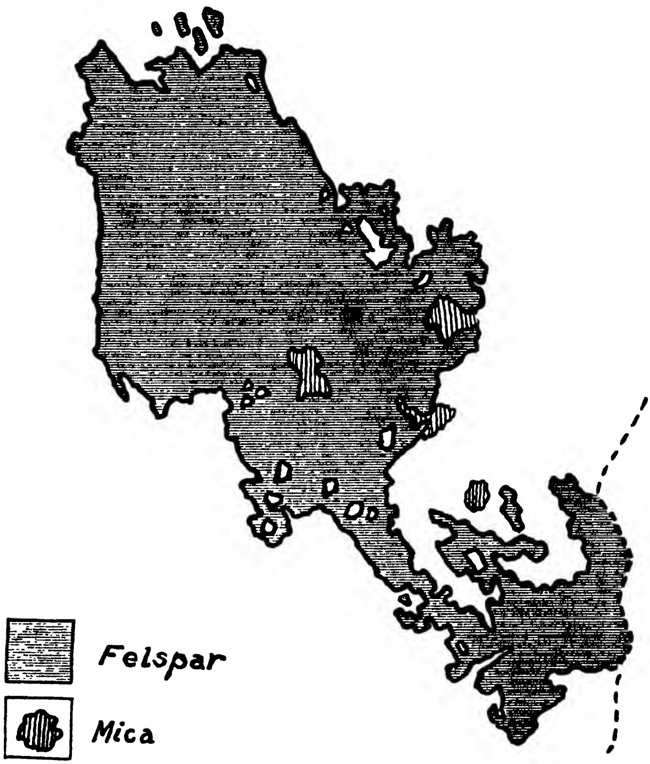
Mineralogy

The description of the mineralogy of this vein is based on a continuous series of thin sections cut from the lower edge of the specimen (Pl. XI) in a plane perpendicular to the photographed surface and to the strike of the vein. The entire width of the vein and of the country rock to the right are covered by these sections.

(*a*) *Quartz*.—(i) In the vein : The vein quartz is white, massive, and faintly cloudy. No structure is visible in the hand specimen, but under the microscope the vein is seen to consist of a coarse mosaic of anhedral interlocking units. Occasional irregular " plumes " of quartz grown perpendicular to the walls show either positive or negative elongation. Strain phenomena are prominent, resulting in mosaics of undulose extinction within individual grains. The plates within these mosaics are often outlined by linear concentrations of inclusions which are prevalent in the quartz, thereby indicating that the concentrations are a direct result of strain. In three dimensions these linear concentrations would appear as planes cutting across the thin section. Occasionally excessive strain has brought about recrystallization of the quartz forming smaller grains at the expense of larger units. Recrystallization zones are mainly confined to the centre of the vein, and often contain extreme concentrations of inclusions and well defined clear patches from which the inclusions have been cleared by strain. The inclusions here are similar to, though smaller than, those in the rest of the quartz, and the boundaries between turbid and clear quartz bear but little relation to the individual crystal grains. Occasionally heavy strain is shown in some grains by the development of parallel lines of inclusions and a peculiar " cross-hatched " polarization mosaic (4). This " felspar " appearance is further enhanced by the development of parallel veinlets of fine-grain quartz with various optical orientations resembling albite lamellae in microcline-perthite. These veinlets are subparallel to the lines of inclusions mentioned above, and where seen are subparallel to the vein walls. The absence of similar phenomena around felspars undergoing replacement by quartz discounts the possibility that the effects mentioned may be ghost structures of completely replaced felspar.

There are various types of inclusions within the quartz. They are principally solid, many are isotropic and have a refractive index considerably lower than quartz. They resemble fluorite especially when they show cubic forms ; their high relief indicates a refractive index too

low for halite. Frequently they contain a fixed bubble, whether liquid or gaseous it is difficult to decide as none of these spherical cavities was seen to contain another bubble. In addition there are a few anisotropic solid inclusions, some of which resemble wispy white mica, but they are too small to be determinable. Tourmaline and chlorite of the late veinlets are not described here. Occasionally liquid inclusions are observed which contain a moveable bubble ; they are generally irregular in shape, but one or two negative prismatic crystals were seen.



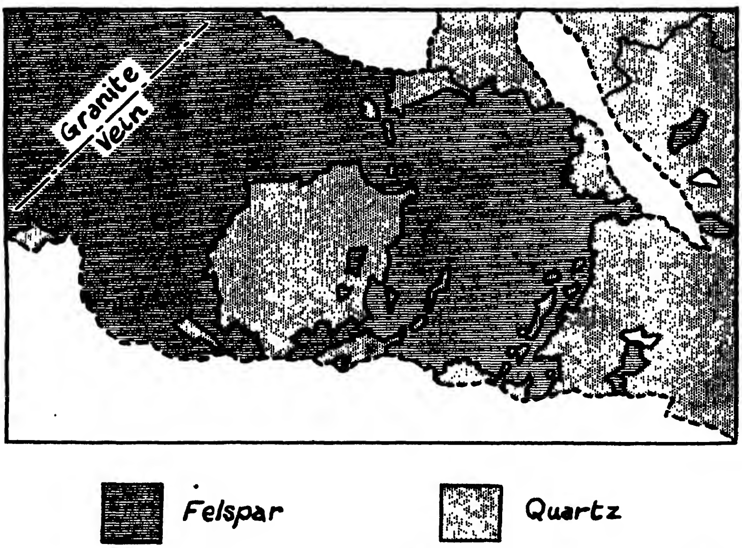
TEXT-FIG. 1.—Shows the corroded outline of a potash felspar crystal in the vein. It is surrounded by quartz which is replacing it. The vertically shaded areas represent aggregates of muscovite. × 15.

(ii) In the granite : Quartz observed in sections cut 5 inches from the vein is essentially similar to the vein-quartz. It is, however, somewhat less strained and rather more free of inclusions. These resemble the inclusions described above.

(*b*) *Potash Felspar.*—(i) In the vein : The felspar is considerably kaolinized with consequent turbidity and low birefringence and the crystals in the thin sections do not show definite microcline twinning. However, some grains in each of twelve crushed samples taken from vein felspars did show indications of cross-hatch twinning. Also the

vein felspars are strained, resulting in an extinction mosaic similar to the strained quartz. On account of strain effects and chemical alteration it is difficult to determine the precise nature of the potash felspar in the vein, but some is perthitic.

The notable feature of the vein felspar is its replacement by quartz. The evidence for this is conclusive ; all stages are present from corroded crystals (see Text-figs. 1 and 2) to small scattered relics in optical continuity (Text-fig. 2). Residual pools of felspar often have wispy muscovite developing on or near the replacement front, probably representing a part at least of the liberated potash and alumina. These relics are not necessarily surrounded by quartz of one optical orientation, but



TEXT-FIG. 2.—The felspar is part of a large crystal in the granite projecting into the vein. That part which is in the vein is considerably strained. Note the isolated blebs, optically continuous with the main felspar, and the typical replacement boundaries between the quartz and the felspar. × 18.

strain effects may obscure a fabric relationship between felspar crystal and replacing quartz.

(ii) In the granite : The predominant potash felspar of the granite is microcline, but here again the cross-hatched twinning may be poorly developed only in patches or on a scale that is almost submicroscopic. Considerable difficulty was experienced in the determination of these felspars. They are commonly perthitic and show Carlsbad twinning. Kaolinization and strain are not so prevalent, though zones of strain do traverse the granite near the vein and in a direction parallel to the strike of the vein. The principal alteration is sericitization (or muscovitization ?) : wispy white mica develops in the centre of the felspar—the flakes may be haphazard or orientated in crystallographic planes.

(iii) In the contact zone: Greisenization of the felspar results in its replacement by veins or pools of medium to fine-grained muscovite and quartz; fluorspar and apatite are notable accessories. Evidence of silicification may be seen, but on a smaller scale than in the vein. Kaolinization is less intense than in the vein. It is interesting to note that where felspars project into the vein one or more of the following changes may be observed: (*a*) kaolinization becomes more intense; (*b*) strain effects increase; (*c*) there may be a very slight change in the extinction position; (*d*) perthite lamellae may be rearranged; (*e*) in one case a chequered effect resembling vague cross-hatch twinning died out on passing from the granite into the vein (Text-fig. 2). A felspar in the contact zone ½ inch from the vein was seen to show the effects (*a*), (*b*), (*c*), and (*d*) where it was traversed by a shear zone parallel to the contact; small fractures which had developed were filled with fluorite.

(*c*) *Plagioclase.*—Albite-oligoclase occurs only in the granite as subhedral crystals, interstitial grains, and in perthite lamellae and occasionally appears to replace potash felspar. In general it has suffered considerably from alteration and replacement, even well into the granite; within the crystals the development of mica, chlorite, and fluorite is common. These frequently form a dense mat almost completely obliterating the original twin lamellae. It seems probable that when plagioclase was replaced by muscovite the calcium set free combined with fluorine to form fluorite, as this mineral always accompanies this alteration of plagioclase. The development of untwinned zones of low birefringence on the edge of the replacing mica "mat" is often seen. These zones appear to consist of potash felspar, but are always too small and too full of incipient mica and fluorite to be determined precisely. Small pools of fluorite were seen developing in the albite lamellae in perthite near the vein. Almost complete replacement by quartz is evident up to 1 inch from the granite/vein contact. Plagioclase was not seen in the vein except as occasional lamellae in perthite.

(*d*) *Mica.*—All that remains of original biotite are a few pleochroic brown patches in secondary chlorite or muscovite.

There are at least two types of white mica, probably three: one is an alteration product of felspars and may be sericitic; another is much coarser and takes the form of interstitial clots and streams. It is associated with quartz, fluorite, and apatite to form a typical replacement greisen often centred about original biotite as shown by residual iron oxides, sphene and murky green pleochroic haloes. The mica is off-white to pale honey colour and may be feebly pleochroic, otherwise it is similar to muscovite. There is a third type of muscovite occurring as large white clear flakes which may be reconstituted secondary mica or an original constituent of the granite. A little muscovite is present in the vein, where it is strained like the surrounding quartz and felspar.

Very little biotite remains, but several stages in its alteration can be observed. Away from the vein it has largely been transformed into chlorite, an alteration accompanied by a development of small wisps of white mica intergrown with the chlorite and in optical continuity. Small grains of black iron oxide are also formed as a by-product of this reaction.

In the greisen zone chloritized biotite is made over to off-white muscovitic mica.

Mention has been made before that mica replacing felspar may follow certain planes within the felspar. Isolated mica flakes growing in any one such plane have the same optical orientation, so that as these flakes grow and eventually coalesce they can form quite large crystals. White mica was also seen replacing felspar with a fabric relationship resembling graphic quartz.

(*e*) *Chlorite.*—This mineral occurs in two forms (*a*) as a stage in the alteration of biotite and rarely (*b*) in rosettes replacing felspar. Faint pleochroism in greens and greenish yellows is usual, with low birefringence (greys to ultrablues, occasionally low yellow tints). Except in the late chlorite-tourmaline veinlets it is a rare constituent of the quartz-felspar vein.

(*f*) *Accessory Minerals.*—The distribution of fluorite in the country rock has been mentioned before under the various mineral headings. This mineral is also present in the vein and may form much of the inclusions in the quartz. Apatite is common as comparatively large equidimensional grains in the greisen. Irregular, brown, zoned tourmaline crystals are occasionally seen associated with quartz in the granite, and as blue to colourless pleochroic needles, in the late veinlets. The brown tourmaline does not appear to be connected with either period of vein formation, and is considered to antedate both. Iron oxides and sphene are associated with altered biotite. Pleochroic haloes in the mica are caused by inclusions, probably zircons, ranging from stumpy crystals to long prismatic needles.

Discussion

From the preceding observations it is possible to formulate the history of this vein. The critical points in the evidence are :—

(*a*) the corroded and residual relics of the felspar in the vein, indicating replacement by quartz ;

(*b*) the observed projection of granite felspars into the vein, and, more especially, the large felspar crystals which project into the granite at both ends, forming a bridge across the vein ;

(*c*) the linear orientation of the felspars in the granite is preserved in those crystals remaining in the vein.

It may be argued that this vein could have been formed by the injection into an open fissure of a solution containing the necessary ingredients for quartz and potash felspar, and that this solution precipitated these minerals which grew in optical continuity with similar minerals in the granite outcropping on the walls of the fissure. Evidence cited in favour of this theory might be the slight variations in properties shown by the felspar crystals on passing from granite into the vein. In view of the three items of evidence given above, such a hypothesis would entail : (1) in the case of felspars passing completely through the vein, the direction of movement during widening of the fissure at any point would have to be parallel with the elongation of the cleaved crystals in order to preserve the original alignment of the felspars ; (2) the injected solution would have to deposit just sufficient felspar to complete such cleaved crystals

and to add to all outcropping felspar—no more, no less ; and (3) after this had taken place the siliceous solution would have to suffer a change in character and start replacing the felspars it had once deposited.

Such a series of coincidences could hardly be expected even in this field of acid igneous geology where quite familiar products, such as granite, can result from most arresting processes.

From the geological evidence it is more reasonable to infer replacement resulting in the localized silicification of the granite to form a vein-like body. This theory is in accordance with the evidence given at the commencement of the discussion, and by the clot of silicification to the right of the vein shown in Plates XI and XII. In this clot replacement is obvious and the features shown by the vein are duplicated, but silicification has not been localized in the same way. It is the sharply defined and parallel nature of the walls of the vein that is so striking. It is considered that the " vein " silicification was localized by a narrow fissure zone consisting of numerous minute to sub-microscopic fissures, rather than by limited diffusion from a central fissure. Movement along this zone was probably in the nature of vibratory oscillations of small amplitude, in any event no appreciable displacement can be seen. Strain and/or metasomatism must, therefore, be responsible for the differences between the felspars in the vein and those in the granite, i.e. (*a*) the reconstitution of perthite lamellae, (*b*) slight variations in extinction positions, (*c*) reconstitution of the felspar as a whole, tending towards loss of inclusions and affecting the twinning, and (*d*) the degree of kaolinization, etc.

It is difficult to sort out the effects produced by the different periods of strain which occurred (i) before silicification, (ii) before the formation of the chlorite-tourmaline veinlets, and possibly (iii) during underground mining. This last is always a problem ; where well developed the effects can often be definitely ascribed to blasting, but they may grade off into structures of doubtful origin.

Replacement alongside submicroscopic fissures is often observed in vein deposits, and in this particular case it is well shown in the earlier stages of the formation of the chlorite-tourmaline veinlets. These veinlets have not been described in this paper, but will be dealt with in future publications on this aspect of Cornish geology.

Any conclusions regarding the nature of the solutions which effected replacement must be purely speculative. In composition they obviously contained considerable silica and the greisen minerals show that the volatile constituents must have included H_2O (in muscovite and sericite), fluorine and possibly P_2O_5 (in fluorite and apatite respectively). It is probable that of these H_2O was the dominant constituent. It seems doubtful whether all the potash necessary for greisenization could have been liberated during silicification of felspar or chloritization of biotite. It is certain, however, that these processes contributed potash to a large extent. Similarly it is open to question whether all the calcium for fluorite was derived from altered plagioclase. It may be inferred, therefore, that some potassium and calcium may have been present as constituents of the solutions.

Concerning the state of the siliceous solutions it is hardly conceivable that there was anything approaching the viscosity commonly ascribed

to magma or even later fluxed pegmatitic magmas. It is probable that the solutions were more or less tenuous, but, in the absence of data regarding the critical phenomena in such solutions, it is hardly justifiable to speculate on their precise nature. In view of the close nature of the channelway (and this cannot be doubted) it is highly improbable that the solutions were under anything but a high pressure. This would preclude the formation of a vapour phase. One other point is that the quantity of fluorite present is totally inadequate to account for the transport of silicon as silicon tetrafluoride. It is probably more true to look upon fluorine as a constituent of the solution acting, in company with the other volatiles, as a flux.

Conclusions

The quartz vein is considered to have formed by replacement of granite. The metasomatizing agent was a fluxed siliceous solution travelling under pressure along a zone of minute fissures. Intense metasomatism was localized in this zone. Replacement, however, was not generally complete ; residual felspars were left in replacing quartz and the vein then resembles a pegmatite dyke in form and mineral assemblage. Some penetration of the country rock was effected, resulting in minor silicification and extensive greisenization. Strain and/or metasomatism was responsible for certain anomalous characteristics observed in the felspar of the vein zone.

Later movements gave rise to a further set of fissures associated with the period of lode formation. Here these fissures are represented by chlorite-tourmaline veinlets.

Acknowledgments

The author wishes to express his appreciation of the facilities provided by Captain C. V. Paull and his staff, at South Crofty Mine, and his gratitude to Professor H. H. Read and Dr. R. M. Shackleton for valuable criticism and suggestions.

References

This paper is of a descriptive nature and only a few typical references were selected ; further relevant publications are given in most of the works cited :—

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(2) Lindgren. Metasomatic Processes in Fissure Veins. *Trans. A.I.M.E.*, vol. 30, 1900.
(3) G. M. Furnival. Quartz Veins of the Great Bear Lake, Canada. *Econ. Geol.*, vol. 30, pp. 843–859.
(4) S. F. Adams. A Microscopic Study of Vein Quartz. *Econ. Geol.*, vol. 15, No. 8, p. 623.

The Genotype of *Cummingella* Reed

By C. J. Stubblefield [1]

The genus *Cummingella* was erected by Reed (1942, p. 653) with the genotype "*Entomolithus* (*Oniscites*) *derbiensis* Martin"; the accompanying generic diagnosis, however, was based, not on the description and illustrations given by Martin (1809), but on the concept of *Phillipsia derbiensis* Auctorum which has prevailed since, at least, the time of H. Woodward's 1883 account published in the Monograph of the British Carboniferous Trilobites. The purpose of this note is to indicate and to attempt to clarify the unsatisfactory nomenclatorial state of both Martin's species and *Phillipsia derbiensis* Auctorum.

Entomolithus derbyensis Martin

Martin's original figured specimens unfortunately have not been traced, but he gave several figures of the fossil which he named "*Entomolithus Onicites* (*Derbyensis*)".[2] He described his pl. 45, fig. 1, to be "Fragments of *E. derbyensis*, as commonly found in black marble"; these are very fragmentary pieces of pygidia and thorax, and, from the figure, would be generally agreed as unrecognizable specifically and doubtfully generically. Figure 2 of pl. 45 is of a rather better specimen, comprising a damaged thorax and pygidium in continuity, and this is described by Martin as "The body of a larger insect of the same kind in common limestone"; here there are 19 or 20 wide axial rings and there is a pygidial border surrounding the posterior 10, or so, lateral segments but the pleural furrows transgress this border and the axis apparently does not reach it. No tubercles are drawn on the axial rings and pleurae. This may be the specimen referred to by Martin on p. 1 of the "Systematical Arrangement" which follows the explanations of his plates as "Specimen b. with smooth segments, a *nucleus*; differs, therefore, only accidentally from the more common examples of the species". Even were this a drawing of one of the group of trilobites centred round *Phillipsia jonesi* Portlock, and such are among the trilobites occurring in the Ashford "marble", it is difficult to understand the shortness and breadth given to the axis in the drawing. As it stands, however, it is very doubtful if this figure would permit a specific identification without the original specimen; there is a strong suspicion, moreover, that it is not conspecific with the original of pl. 45*, fig. 1, which Martin described as "A perfect specimen magnified" and though he did

[1] Published by permission of the Director of the Geological Survey and Museum.

[2] The spelling 'Derbyensis' was the only form used by Martin (1809) in his description of the fossils and that occurred four times: once subsequently, however, he employed the form 'Derbiensis' in that portion of his book called 'A Systematical Arrangement of the Petrifications described in Volume the first with additional Remarks on some of the Species' which followed his descriptions of these, on p. 1. under the headings, Entomolithus, Oniscitae. The spelling first used being that containing the letter 'y', and that having been used repeatedly by the original author, in accordance with the articles of the International Commission of Zoological Nomenclature, it is proposed to retain *derbyensis* as the orthography.

not mention this in words as the type, when commenting on his " very perfect specimen of the *Entomolithus paradoxus* from Dudley " (*Calymene blumenbachi* Auctt.) he wrote that the difference between the two fossils would be readily appreciated on comparing the figure of the Dudley fossil with " the magnified one of *E. derbyensis* in Tab. 45* ". This figure is of a complete trilobite, the cephalic margins are drawn as striated con-marginally except in front where the glabella encroaches on to the border and nearly reaches the front edge. The glabella is widest anteriorly, with a middle lobe, pyriform posteriorly, and apparently with uncurved basal furrows; the eyes are fairly large and the occipital ring bears a median tubercle. Since in the drawing, the cephalic border has been produced posteriorly to meet without interruption the smooth pygidial border, it is probable that in the original the cephalon had long genal spines. The thorax and pygidium are undifferentiated in the figure which shows 18 or 19 post-cephalic segments, each of which axially and laterally carries a row of small tubercles. In his description Martin states that there were 20–24 segments " each marked with a line of very minute tubercles ". Of all the figures this is the only one showing the " striated margin " of the head, the " single minute point or tubercle " on the occipital ring, the post-cephalic segments " each marked with a line of very minute tubercles " of Martin's description. The last figure given by Martin is fig. 2 of plate 45*, which is described as " another specimen of the head, more highly magnified to show the reticulated structure of the tubercles ", which in the text he had referred to as a pair of " large lunated tubercle[s], discovering, in perfect specimens, a reticulated structure, like that of the eyes of living insects, when magnified ". The figure is of a free cheek showing a somewhat coarsely reticulated eye-surface but no genal spine.

Workers closely succeeding Martin, such as Phillips and Portlock, interpreted *E. derbyensis* on the basis of his pl. 45*. Phillips (1836, p. 240), in fact, stated that his species *Asaphus globiceps* " agrees better than any other which I have seen with *E. Derbiensis* Martin pl. 45* 1 ". Portlock (1843, p. 312), however, in his description of *Griffithides globiceps*, stressed that Martin had stated the eyes to be reticulated in *E. derbyensis* which, moreover, had a small tubercle on the neck segment and minute tubercles on the other segments, three characters which he stated had been observed in *Phillipsia* but not in *Griffithides globiceps*. On the other hand, he noted that there were certainly some points of resemblance particularly in the form of the cephalon and glabella, the position of the eyes and the striated margin, and he concluded that " although a doubt must exist as to the identity of Professor Phillips and Martin's species, and even genera ", there was some evidence for relegating them to the same genus.

Martin gave no individual localities for his figured specimens but he stated that his fossil was " principally met with in the black marble at Ashford where it very rarely occurs in a perfect state ", and again he wrote (p. 1 of the Systematical Arrangement) " In the black marble quarries at Ashford—On Bakewell Moor, in rotten-stone ". There is in the museum of the Geological Survey, among several species of trilobites labelled Ashford, certainly a cephalon with a waisted glabella which Reed would have referred to his genus *Cummingella*, but one fails to find any

resemblance between this and Martin's description and figures except that the locality is one of the two given by Martin. Furthermore, of the other black limestone specimens in the same museum, from Ashford and district, there are two pieces, lithologically similar to the Ashford " marble ", labelled Bakewell, which show cephala of the kind figured by Martin, pl. 45*, fig. 1—for the glabella transgresses the front margin and almost reaches the front, and is pyriform posteriorly with two basal lobes; the cephalic margin is striated laterally and produced into substantial genal spines; large faceted eyes are also present. The surface of the basal lobes agrees with Martin's description of the glabella as being " under a glass, apparently somewhat rough and scabrous "—the remainder of the glabellar surface is largely decorticated. In one such specimen, No. 33698, a pygidium is associated, which shows 15 axial rings, all with a tuberculated posterior edge and 10 lateral pleural ridges each showing a line of smaller tubercles. If one may assume that the thorax was of 9 segments, the usual number in this group, then the total number of post-cephalic segments would be 24, the greater extreme of the 20–24 mentioned in Martin's description. The first three pygidial pleural ridges show the interpleural boundaries between the fused pleurae as thin depressed lines and the most anterior of these transgresses on to the pygidial border ridge. These specimens appear to be referable to *Weberides* Reed, 1942; the interpleural furrows produce in the pygidium the bifurcated pleurae mentioned in Reed's description of that genus. If therefore, the complete specimen illustrated by Martin, pl. 45*, fig. 1, is selected as the lectotype of *Entomolithus derbyensis*, the correct generic reference for this should be *Weberides*. Pygidia of similar type are known from the black limestone of Ashford, which is but little over a mile from Bakewell. These are the only two localities specially mentioned by Martin.

Phillipsia derbiensis Auctorum

The changing of the concept of Martin's species seems to date from the publication of the " Description des Animaux Fossiles . . ." when de Koninck (1844, p. 595) adopted Portlock's genus *Phillipsia*, but he placed *Griffithides* Portlock into the synonymy of *Phillipsia* and (op. cit., p. 601) accepted all four of Martin's figures as conspecific and arranged these with many other species as *Phillipsia derbyensis*. He considered *Asaphus seminiferus* and *A. granulatus* of Phillips " comme des simples variétés d'âge de *P. Derbyensis* " ; he also merged *A. raniceps* Phillips and *P. jonesii* var. *seminifera* ? of Portlock into *P. derbyensis*. He dismissed previous comparison of Martin's species with *P. globiceps* as wrong on the grounds that Martin had figured the eyes as " grands, droits et reticulés ", whereas in *P. globiceps* they were " petits, lisses et obliques ". De Koninck selected no type of this species, but he figured a Belgian specimen of which Weber (1937, p. 131) has criticized the reference to *P. derbyensis* on other grounds for he considers that the figure given by Woodward, 1883, pl. i, fig. 2, is " the typical form of *P. derbiensis* ". De Koninck's illustration differs from Martin's very considerably in glabella characters ; furthermore it lacks the forward glabella expansion seen in Phillips' *A. raniceps* and in Portlock's *P. jonesii seminifera* ? The neck

ring lacks the tubercle and the post-cephalic segments lack the minute tubercles described by Martin. Even if de Koninck's figure is compared with Martin's pl. 45, fig. 1, there is little agreement for the pygidial furrows do not transgress on to the borders as they do in Martin's figure. It would appear, therefore, that de Koninck was not illustrating Martin's species, neither was Salter (in Salter and Woodward, 1865, fig. 111) who gave Portlock (pl. xi, fig. 5) as a reference of the species.

Woodward (1883) did not follow de Koninck in uniting *Phillipsia* and *Griffithides* as one genus, but he was not very critical of that writer's treatment of *Phillipsia derbyensis.* Though Woodward quoted the greater part of Martin's description of *E. derbyensis,* as a footnote on p. 14, he stated : " In the same work on plate xlv*, figs. 1, 2, Martin represents what seems to be intended for *Griffithides* (*Phillipsia*) *seminifera* Phil. sp. hereafter described." These figures, however, are not mentioned elsewhere in Woodward's monograph. It would seem, therefore, that the illustration which Martin specially singled out as the most typical of his species was summarily dismissed from Woodward's concept of the species. There is, however, no statement in Woodward's description which can be interpreted to be a designation or citation of a type for the species.

Woodward's illustrations are those from which *Phillipsia derbyensis* owes its current usage, particularly his pl. i, fig. 2, portraying a complete trilobite, which was used largely in the restorations given as figs. 6–9. He interpreted the species widely, though not so widely as did de Koninck ; his fig. 1 he stated to be a new figure of the type of *Asaphus raniceps* Phillips from the Gilbertson Collection from " Bolland " ; his fig. 3 from Settle is of a cephalon which shows relatively smaller eyes than those shown in figs. 1 and 2, and the figs. 4*a* and 5 also show differences. It is, however, fig. 2 and the restoration based on it as fig. 6 which have received the widest reproduction and it is on the original of these figures that attention will now be turned. This specimen was stated by Woodward to be in " the Museum of Practical Geology, Jermyn Street, S.W." and the locality is recorded as " Longnor, Staffordshire ". This specimen is before me in this museum where it is registered as No. 63037. It is mounted on a wooden tablet numbered 36/77 with a locality label " Longnor " and Woodward's label that this was the original of his fig. 2. Affixed to the matrix of the specimen itself is, however, a small fragment of a printed label of the pattern usually seen in this museum on specimens collected by the Ordnance Survey of Ireland in Portlock's time. Furthermore the fine-grained character and pale pink colour of the limestone matrix is identical with that seen in specimens numbered 63031–63036 from Clonfeacle, Tyrone, which constitute the original material of the species *Phillipsia jonesii* Portlock (1843). All but two of these bear Ordnance Survey of Ireland labels and one has a complete label showing the printed grid of which a similar fragment remains on the torn label on specimen 63037. The tablet carrying Nos. 63031–6 is labelled 36/80 formerly 38/24, which last is the case and tablet number relating to the specimens listed under those numbers as *P. derbiensis* on p. 103 of T. H. Huxley and R. Etheridge, " Catalogue of the Collections in the Museum of Practical Geology," 1865. That reference, furthermore, shows that in 1865 there were seven and not merely six specimens on that tablet as now. A reference

to Portlock's original plate, furthermore, shows that unless specimen No. 63037 is the original of his pl. xi, figs. *5a*, *5b*, stated by him (1843, p. 308) to be his illustration of *Phillipsia jonesii* var. *seminiferus* ? Phillips, that figured specimen is missing from our collections. As will be seen from Woodward's illustration (1883, pl. i, fig. *3a*) the trilobite is preserved with a flexure between the cephalon and the thorax ; if the cephalon is measured separately along its axial length and the thorax with the pygidium similarly treated, these measurements, 10 mm. and 18 mm. respectively, agree with those shown in du Noyer's drawing in Portlock (1843, pl. xi, fig. *5a*) ; the breadth measurements are also in agreement ; on p. 308, Portlock gives the total length of the specimen as 1·2 in., du Noyer's figure shows 1·1 in., a figure with which I agree measuring as above described. From these various pieces of evidence I am led to the conclusion that specimen No. 63037, stated to be the original of *P. derbiensis* Woodward (1883, pl. i, fig. 2) is also the original of Portlock 1843, pl. xi, fig. 5 and that the locality is properly Clonfeacle, Tyrone, Ireland, and not Longnor, Staffordshire. I have examined the suite of specimens preserved from Clonfeacle and named *P. jonesii* by Portlock and have found that with a hand lens tubercles can be seen on the posterior edge of the pygidial segments both on the axial rings and on the pleurae, as in specimen 63037 from which they were described by Portlock (1843, p. 308). In specimen 63037, Portlock's var. *seminifera* ? Phillips, the cephalon is 10 mm. long and 12 mm. wide posteriorly (were it preserved flattened dorso-ventrally it would be 17 or 18 mm. probably) ; in specimen 63031, the original of Portlock's pl. xi, fig. *3a*, *P. jonesii*, the cephalon length is 9 mm. and the width, approximately 10½ mm., there is damage laterally ; Portlock considered the differences between *P. jonesii* and its supposed variety to be " minute " ; I can see no reason to think that they are other than that the specimens are different developmental stages of the same species. Phillips' species, *Asaphus seminiferus*, has been made the type of a genus *Metaphillipsia* (Reed, 1943, p. 57) ; whether this genus is to be interpreted in the sense Phillips described and figured his species or as it was described and figured by Woodward in 1883, neither concept would include the form which Portlock referred to as *P. jonesii* var. *seminifera ?*.

Conclusions

There is no doubt that those trilobites closest to *Phillipsia jonesii* Portlock have been known during the past fifty years or more as *P. derbiensis* or the *P. derbiensis* group and that Reed's generic diagnosis showed clearly that he had this group in mind when he erected the genus *Cummingella*. It is to be regretted, however, that he gave as genotype, what in the words of Opinions 65 and 168 [1] of the International Commission on Zoological Nomenclature is " an erroneously determined species ", namely " *Entomolitus* (*Oniscites*) *derbiensis* Martin ", a form that here is claimed to belong to the genus *Weberides* which Reed described in

[1] The latter opinion was published as vol. 2, pt. 38, pp. 411–430, 1945, of the Opinions and Declarations rendered by the International Commission on Zoological Nomenclature, Queen's Gate, London.

1942 in the paragraph preceding that in which he erected the genus *Cummingella*. It seems to me that, following the Opinions above referred to, the genus *Cummingella* must be " regarded as of doubtful status " and I propose to submit a case to the Commission that the rules be suspended in order that *Phillipsia jonesii* Portlock (1843) be the genotype of *Cummingella* Reed (1942) instead of *Entomolithus Onicites derbyensis* Martin (1809). A selection of *P. jonesii* as genotype would have the advantage that the type material is extant whereas that of Martin's species is untraced, and of his figures, only one has any hope of specific identification ; it is that figure which has been chosen above as the figure of the lectotype.

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Cravenechinus, a New Type of Echinoid from the Carboniferous Limestone

By Professor HERBERT L. HAWKINS, University of Reading

(PLATE XIII)

THE remarkable specimen here described was collected in 1938 by Mr. W. S. Pitcher during an excursion of the Chelsea Polytechnic Geological Field Club to Yorkshire, and was presented by him to the British Museum in December of that year. The specimen was found in a stone in a dry-wall, but there is little room for doubt that it came originally from the immediate vicinity, for the matrix can be matched with part of the D_1 limestones exposed there.

By the courtesy of Mr. L. Bairstow the specimen was sent to me for description, but before my study and account of it could be completed circumstances arose to enforce postponement, and it has only recently been " disinterred " from a secure hiding-place. It is unfortunate that the report of such an interesting discovery should have been so long delayed ; but civilization has been in retreat, if not in eclipse, since 1939. Here at last is an account of the most strange and unexpected Echinoid that I have ever handled.

GENERAL DESCRIPTION

The specimen consists of a small piece of earthy, more or less crystalline limestone ascribed by Mr. G. Bond to a " bed some 25 feet thick just below the local equivalent of the *Cyrtina septosa* band in D_1 ". It came from a wall on the northern slope of Butter Haw Knoll, near Skipton, Yorkshire, just below the 900 ft. contour. Embedded at one end of the block is the adapical part of a segment of the test of an Echinoid, comprising an interambulacrum and half of each of the contiguous ambulacra. The segment is very slightly convex longitudinally and even less so transversely, but it shows no trace of dislocation or compression. At the ambital margin there is a very sudden, and apparently unfractured, curvature. The impression given is of a very depressed subconical form with a completely rigid test and a more or less flat base.

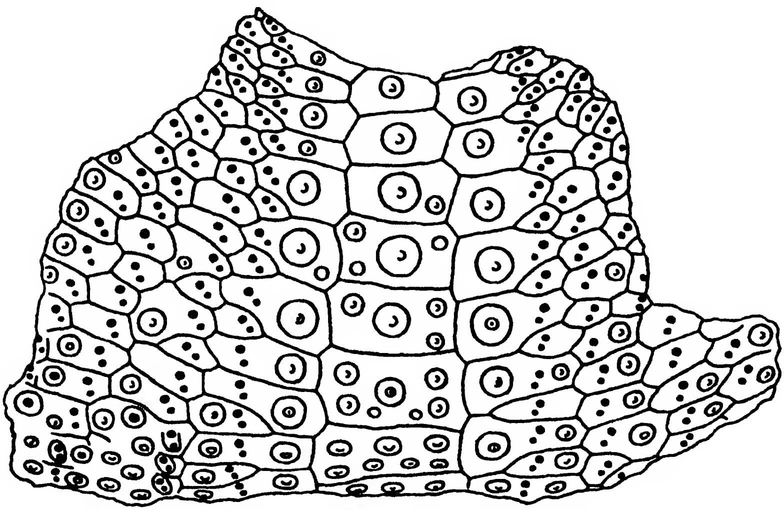
Most of the surface has been somewhat weathered, so that the finer details of its ornament are lacking ; but in compensation the plate-sutures are etched very clearly. It has been possible to dissect out a small part near the ambitus and so to expose the true character of the tuberculation and other superficial details.

The adapical limit of the preserved test does not reach to the apical system but probably approximates to it. If this is so, the apical system must have been quite exceptionally large—something of the order of 15 mm. in diameter, with the complete test about 40 or 45 mm. across. The preserved part of the test is about 14 mm. long—12 mm. almost flat and 2 mm. on the ambital fold. Eight interambulacral plates are present and there are 14 to 16 pore-pairs in each ambulacral column. The interambulacra widen from 2 mm. adapically to nearly 4 mm. at the ambitus, while each half-ambulacrum widens from 5 mm. to 11 mm. correspondingly. The test was therefore mainly built of ambulacral elements, since

the ambital proportions will have been 4 mm. of interambulacrum against 22 mm. of ambulacrum.

Detailed Description

The Interambulacrum.—The outstanding feature of this area is that throughout its visible extent it consists of a single column of plates vertically superposed. These plates are irregularly hexagonal, with the width almost twice the height. They seem to be fairly thick, though not nearly as massive as those of *Melonechinus* or *Palaeechinus*. There is no trace of any sort of overlapping or flexibility here or in the ambulacra. The adradial suture is not a symmetrical zig-zag, since the number of the contiguous ambulacral plates is not quite the same, the eight visible interambulacrals fitting on to nine or ten ambulacrals.



Text-fig. 1.—Outline drawing of *Cravenechinus uniserialis*, × 4 approx. Except for restoration of some of the tubercles, the figure is not diagrammatic. Peripodia, etc., are inserted only where seen, but doubtless existed elsewhere before their removal by weathering.

Each plate bears a median tubercle. The first two from the adapical end have no others, but the rest show a progressive introduction of others (at first at the plate-corners) until at the ambitus there are as many as seven tubercles on a plate. These are arranged in two transverse lines, and the median tubercle is not noticeably different from the rest. All of the tubercles that retain their mamelons show these to be perforated; the bosses are very prominent, but the scrobicules are superficial and ill-defined. The general proportions of the tubercles resemble those of such modern forms as *Echinus*, being far below those seen in *Archaeocidaris* but much above those usual in the Perischoechinoids. The interambulacral tubercles are, on the average, a little smaller than those on the adradial parts of the ambulacra.

The Ambulacra.—Each half-ambulacrum shows four well-defined rows

of pore-pairs that form straight and practically equidistant lines except in the congested adapical parts. The pores of a pair are steeply inclined, and in some cases almost vertically superposed. Each pair is enclosed by a peripodium (except where this has been weathered away); and the pores were separated by a granular prominence. The upper member of each pair is notably larger than the lower.

The nature of the plating is best appreciable by reference to the drawing (Text-fig. 1), but attention may be directed to some outstanding features. The outer (adradiad) row of pores occurs in a double series of interlocked plates, recalling in their disposition the pattern seen in the petals of *Clypeaster*. Of these plates the outer (adradiad) ones extend across the full width of the column, and are scarcely inferior in size to the interambulacrals with which they are in contact. The tapering perradiad ends of these plates carry the pores, and are separated (with occasional exceptions) by small occluded plates whose pores are in alignment with the others. The second row of pores occurs near the adradiad ends of a column of plates that are mostly " primaries ", but with a few " demi-plates " intercalated. The third column is similar but consists exclusively of primaries, as does the fourth, where the perradiad end of each plate carries a fairly prominent tubercle.

Each half-area is bordered by continuous rows of large tubercles (one adradial, the other perradial); a few scattered tubercles have survived the weathering of the true " poriferous zones ", but at the ambitus a plentiful tuberculation occurs among the pores.

Comparisons and Classification

A first glance at this fragment at once suggests comparison with *Melonechinus*, where the ambulacral areas have much the same appearance and proportions. But, putting on one side the single interambulacral column, the large-scale tuberculation, and the presumed shape of the test, it is in the structure of the ambulacra that the most complete contrast emerges. Compared with that of *Melonechinus* the ambulacrum of *Cravenechinus* may be said to be " inside-out ". In all polyserial ambulacra, Palaeozoic or later, it is the rule that the perradiad plates are the largest, and usually that the adradiad plates are the smallest. Here, however, although the perradiad plates are no smaller than the others, the adradiad ones are relatively enormous, and at the same time carry their pores at the " wrong end " when judged by normal Echinoid standards.

The uniserial interambulacrum, and the approximate alternation of its plates with the contiguous ambulacrals, invites, indeed demands, comparison with *Bothriocidaris*. In those two characters *Cravenechinus* comes to mitigate the splendid, but embarrassing, isolation of the much-debated Ordovician genus. In all other respects, however, the relation of the two types is one of contrast.

The shape of the test is conjectural, but if, as I believe, it resembled that of, say, *Holectypus depressus*, it will have been quite unlike any of its stereosomatous companions, which were almost all either spheroidal or ellipsoidal.

On the evidence of a single fragment I do not feel justified in proposing a new order of Echinoids, if only from the lurking fear that the individual

may have been teratologically abnormal. For the present I prefer to regard it as an aberrant member of the Melonechinoida, differing from its fellows chiefly in the inverted structure of its ambulacra. There is nothing " improper " in the conception of a Melonechinoid with a single interambulacral column. Most members of that order have an odd number of columns of interambulacral plates, and *one* is itself an odd number. Moreover, the Melonechinoid interambulacrum seems always to start (at the peristomial margin) with a solitary plate ; so that a uniserial area can be explained as the result of the retention throughout life of a condition that is more usually elaborated in the ontogeny of other types.

I find it impossible, however, to force *Cravenechinus* into any recognized family, and submit the following systematic scheme.

Family CRAVENECHINIDAE *fam. nov.*

Melonechinoida (?) with a depressed conical form. Interambulacra uniserial. Ambulacra multiserial, the adradiad columns of large plates with perradially placed pore-pairs. Pore-pairs in peripodia, the upper pore larger than the lower. Tuberculation prominent and abundant, mamelons perforate.

Genus CRAVENECHINUS [1] *gen. nov.*

With the characters of the family.

Genotype CRAVENECHINUS UNISERIALIS *sp. nov.*

Test about 40–45 mm. across, depressed, conical, flattened adorally. Apical system probably large. Interambulacra of one column of plates, each about twice as wide as high, with a large median tubercle on each plate, and up to six additional tubercles of almost the same size on ambital plates. Ambulacra multiserial, with eight vertical rows of pore-pairs. Adradiad column consisting of large plates roughly alternating with the interambulacrals, and embracing small occluded plates ; its row of pore-pairs perradiad. Large tubercles on the adradiad parts of the adradial column and on the perradiad parts of the perradial column.

Horizon and Locality.—Carboniferous Limestone (D_1, Viséan) ; Butter Haw Knoll, nr. Skipton, Yorkshire.

Holotype.—Brit. Mus. Geol. Dept. no. E 32370.

THE SIGNIFICANCE OF CRAVENECHINUS

The outstanding significance of the discovery of this extraordinary Echinoid is surely its emphatic reminder of our ignorance. The Carboniferous Limestone of the Craven district has been intensively studied by generations of geologists ; and one might have assumed that a reasonably complete knowledge of its fauna had been acquired. And now, as late as 1938, a macroscopic fossil is found that reveals the existence of a totally unexpected association of structures in a group where considerable standardization seemed to prevail. Evidently the time is not yet when we can construct theories with any confidence that we have enough evidence to claim them as creeds.

[1] Named from the Craven district of Yorkshire.

The existence of a single column of interambulacral plates is a feature capable of diverse interpretations. To those who regard this character in *Bothriocidaris* as a primitive feature, the interambulacrum of *Cravenechinus* will seem to be atavistic ; to the opponents of that view, it must appear as an extreme case of specialization. At least it is now possible to say that the sort of thing that happened in the case of *Bothriocidaris* did actually recur later in Echinoid history. There may also be agreement that the presence of the single column is in some way to be connected with the unusual shape of the test and the great width of the ambulacra. The increase of girth at the ambitus is almost wholly attained by ambulacral expansion. The full range of expansion of the interambulacrum is limited between 2 and 4 mm. Hence the single plate that sufficed to span it near its poles can, without much modification, reach across it at the equator.

On the other hand, it must be admitted that similarly narrow interambulacra in such genera as *Lepidesthes* may be constructed of three or more columns, so that in *Cravenechinus* there was ample room for more than one column. The plates are, actually, much wider in proportion to their height than is usual among Palaeozoic types ; hence the argument put forward by Mortensen (1940, p. 345) as to the presence of single columns only when there is no room for more certainly fails to satisfy in this instance. The association of specialized and primitive characters in a single organism is sufficiently familiar to make plausible the suggestion that in *Cravenechinus* the interambulacrum is either retarded or retrograde in morphogeny, notwithstanding the advanced state of the ambulacral structure.

The wide separation of the outer pore-rows from the adradial suture is apparently unique. The only other case of a perradiad position of the pores in the adradial column known to me is that figured by Jackson (1912, pl. lxvii, fig. 5) in *Proterocidaris*. There the plating-structure is comparable with that of *Cravenechinus* (though the proportions of the plates are quite different) ; but since the figure shows the inner surface, the position of the pores does not necessarily correspond with their external situation. In any case, the adradial columns of the ambulacrum of *Proterocidaris* are apt to be overridden by the imbricate interambulacrals, and so could not have carried the large tubercles that are so striking a feature in *Cravenechinus*.

The result of this arrangement is to double the effective width of the otherwise very narrow interambulacral region by incorporation with it of the imperforate adradial parts of the adjoining ambulacra. This ensures a rigidity of the adradial suture that will have greatly strengthened the cohesion of the test as a whole. If we associate with this character the "*Echinus*"-like proportions of the radioles and the (assumed) depressed shape of the test, it is possible to regard *Cravenechinus* as adapted for life in fairly turbulent surroundings. It must, indeed, when alive, have looked very much like a small, flattened species of *Strongylocentrotus* ; and although that superficial likeness was based on a fundamentally different plating-structure, we may assume that there was a similarity in the manner of life.

Most of the Palaeozoic Echinoids seems to have been adapted for life in a fairly sheltered environment, with precautions (such as flexibility

CRAVENECHINUS UNISERIALIS. Gen. et sp. nov.

or globular massiveness) against chance dislodgement. *Cravenechinus* is, so far as I know, the only one of them that seems to have chosen an environment similar to that frequented by the more advanced Echinidae of the present day. But while very " modern " in its general appearance, it was more extraordinary in its intimate structure than any of its notoriously strange contemporaries.

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EXPLANATION OF PLATE

Untouched photograph of *Cravenechinus uniserialis* gen. et sp. nov., Carboniferous Limestone, nr. Skipton, Yorks. (Brit. Mus. Geol. Dept. E. 32370.) × 5½ approx. Compare with Text-fig. 1, p. 193.

CORRESPONDENCE

THE CORNISH MICA-TRAP PROBLEM COMPARED WITH A SEQUENCE OF ROCKS IN MALAYA

SIR,—One of the unsettled problems of Cornish geology is the age of the mica-traps, or minettes, relative to the elvans, or quartz-porphyries and felsites. Which came first ? The general opinion is that the mica-traps came last. For instance H. C. Versey (1929, p. 314) says : " The mica-lamprophyre dykes are probably of slightly later age." This opinion is based on the resemblance of the mica-traps to some exceptional rocks found among the Exeter Traps intercalated with sediments believed to be of Permian age and intrusive into Culm (Ussher and Teall, 1902). On the other hand, J. H. Collins and J. B. Hill did not hold that view. Collins (1884, p. 197) in a description of the Cornish mica-traps wrote : " A little farther to the west, in Gloweth Farm (near Truro), a series of pits on the south side of the turnpike road marks the position of another vein. This passes through Liskes in a N.N.E. direction to Boscolla, where it is intersected by one of the ordinary felspar-porphyries of the district." Hill (1906, p. 80) mentioned this record, but hesitated to accept it. In 1901, however, Hill evidently was of the opinion that the elvans came after the mica-traps (1901, pp. 32, 33, and 34). When I was a junior member of the Geological Survey in 1902 and 1903 in Cornwall the official view was that the mica-traps came last and I saw nothing to upset it. I am indebted to Mr. J. Robson of the Camborne School of Mines for telling me that no decisive evidence has been found in recent years.

My object in writing this letter is to point out that in Malaya very clear evidence has been found of granite being cut by lamprophyres and then by later acid rocks (1931, table on p. 47). Moreover, two months before leaving Malaya in May, 1931, I saw in the Bukit Ubi granite quarry, near Kuantan Town, granite cut by dolerite dykes, followed by dykes of quartz-porphyry cutting both the granite and the dolerite dykes. My record of this, however, was received with hesitation similar to that

evinced by Hill towards Collins, therefore I decided to defer publication until someone confirmed it, which has been done by a member of the Geological Survey of Malaya, Mr. F. H. Fitch who was stationed in Kuantan and is now in England. He tells me there is no doubt of the sequence and that he has seen xenoliths of dolerite in a quartz-porphyry dyke. It does not follow of course that because a certain sequence of igneous rocks has been proved in Malaya a similar sequence must be accepted for Cornwall, roughly 8,000 miles away, without evidence equally clear; but it must be conceded that Collins, who unfortunately was sometimes vague in differentiating between igneous rocks, may have been quite correct when he described a mica-trap as being intersected by a felspar-porphyry, and that he and Hill were right in considering the elvans later than the mica-traps.

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THE CONCENTRATION OF MANGANESE ORES

SIR,—In his Bulletin (1943) on the Geology of the Nsuta manganese ore deposits Mr. H. Service has shed much light on an occurrence whose economic importance has been no less than its scientific interest for some thirty years. The deeper working of the deposits appears to have demonstrated an original—or at any rate a geologically ancient—concentration of manganese ore in the Birrimian rocks. It is of interest to notice the similarity between the Birrimian rocks of Nsuta and those of Tassawini, Barama River, British Guiana, where a deposit of manganese ore has been described by Dr. D. A. Bryn-Davies.

The authors of an earlier paper (1930) were mainly concerned in 1926 with the superficially enriched ore which was then the principal product of the Nsuta mines. In suggesting that the importance of meteoric weather was overstressed by Bishopp and Hughes, Mr. Service has surely overlooked one of our more important arguments and does not appear to have adduced it in his own paper. I refer to the widespread occurrence and weathering of pyrites in the Birrimian rocks. We recorded the mineral in basic carbonate-talc-chlorite schist, as well as in the intrusive felspar-porphyries which are closely associated with the manganese ore-bodies; Service mentions its presence in the "Green Schists" and phyllites (pp. 13 and 14 of his work).

Sulphuric acid seems to be of special importance in the solution and redistribution of manganese. For example, sulphate of manganese solution is hydrolyzed so rapidly in the soil that it is sprayed on to the foliage of plants suffering from manganese deficiency, instead of being applied at the root. A little sulphuric acid should accordingly produce a relatively large effect in a manganese deposit, for it will go on reacting until fixed by some more stable base. There is thus no prima facie objection to the formation of ore of high purity from a very low grade primary phyllite with a manganese content of the order of 1 per cent (Service, 1943, p. 9; Bishopp and Hughes, 1930, p. 167).

This of course does not traverse Service's inference that the principal ore-bodies at Nsuta existed in pre-Devonian time; the question is how far these have been reconcentrated by hydrothermal agencies as well as by later meteoric action. Developing the suggestion made by R. H. Rastall (1944), it would seem possible that sulphuric acid may play as important a part in the secondary oxide enrichment of manganese as it does in the secondary sulphide concentration of copper.

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11*th April*, 1946.

REVIEWS

Petrological Studies on some Basaltic Rocks from East Greenland. By T. Krokström. *Meddelelser om Grönland*, Band 103, No. 6, pp. 73, with 2 plates and 5 figures, 1944.

This memoir contains a detailed description of some rock specimens from the Scoresby Sound region collected during Dr. Lauge Koch's expeditions between 1929 and 1934, and it includes an appendix by Professor Backlund on their field relations.

In the petrographical descriptions they are classed as olivine-dolerites, plagioclase-porphyrites and basalts, but it is explained that the dolerites and basalts are really the same, differing only in texture. The field relations of the two main groups are imperfectly known, but according to Professor Backlund a dolerite dyke has been seen cutting a porphyrite. An older complex of alnöitic lamprophyres is not here described.

A most elaborate and careful description is given of all the constituent minerals, and some analyses, due to Dr. Sahlbom, are subjected to every form of calculation, such as is now so fashionable in petrography: norms, molecular proportions, Niggli numbers, and the rest of it. In

one instance a comparison of the norm with a "geometrical analysis" brings out an interesting point, namely that the norm shows 48·49 per cent of felspar, while the mode gives only 34·2 per cent, a difference of over 40 per cent. This affords a useful comment on the value of all these elaborate calculations so far as the actual rock itself is concerned. It is to be feared that rock types in modern petrology tend to develop by means of slide-rules and log-books, rather than by magmatic differentiation or any other natural process.

The plagioclase-porphyrites do not really seem to differ very much from the dolerites and basalts except in possessing a distinctly porphyritic structure. The norm shows a little quartz and no olivine, but the SiO_2 is only about 1·4 per cent higher, and some olivine is present in the mode.

As before indicated the basalts are much finer grained than the dolerites, but otherwise very similar. The minerals in order of abundance are plagioclase, pyroxene, iron ores, and olivine, the last only as a few very small grains. All the specimens here called basalt seem to have come from dykes.

A single specimen of a curious rock from Hurry Fjord, Liverpool Land, is described as an anorthoclase rock: it consists of anorthoclase felspar and biotite, all of very fine grain, and contains relics of what appear to be quartz-xenoliths more or less replaced by calcite and felspar. This rock seems to belong to the lamprophyre family.

R. H. R.

ILMENITE, MONAZITE, AND ZIRCON AND GEMS AND SEMI-PRECIOUS STONES OF CEYLON. By D. N. WADIA and L. J. D. FERNANDO. *Professional Paper 2, Department of Mineralogy, Ceylon*, pp. 73 with 2 plates. Colombo, 1945.

This publication comprises two separate papers. The first is a new and up-to-date version of a report originally published in 1926. Since that date there has been a good deal of change in the economic value of the minerals dealt with in it. For example, owing to the decreased use of gas mantles monazite is now valuable less for its thorium content than for cerium, for which there are now important uses, especially in pyrophoric cerium-iron alloys for pocket lighters, and for cerium compounds for protecting cloth from mildew. Again the demand for titanium for paints is now important. There are also new uses for zircon. There seem, however, to be no considerable changes in the available sources of these minerals, namely beach-sands of great extent and high grade.

From time immemorial the gem gravels of Ceylon have been famous: they seem to produce all the usual gems except the diamond, but perhaps they are most famous for sapphires. From a definite area in the Ratnapura district comes 95 per cent of the output of gems and it may be said in general terms that none of them are worked *in situ* in the original rocks, except some moonstones, tourmalines, and garnet, which are not important. Practically all the valuable gems are derived by the ordinary processes of denudation and deposit from the Khondalite series, and mainly from pegmatites therein.

It is noted that the local methods of gem-cutting are extremely primitive, and that expert instruction is much needed.

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Notes on Some Lamellibranchs from Quarrel Hill, Girvan

By the late Dr. F. R. C. Reed

(With a Note on the Quarrel Hill Section by J. L. Begg.)

(PLATE XIV)

A SMALL collection of fossils from the Upper Ordovician of Quarrel Hill, Girvan, made recently by Mr. James L. Begg, is remarkable for the number and character of the lamellibranchs, several of which appear to be new. Their affinities are chiefly with those of the Ordovician of the United States and are consequently of special interest.

Amongst other fossils from this horizon at Quarrel Hill are *Encrinurus multisegmentatus* (Portl.), *Cryptolithus gibbifrons* (McCoy) var. *praeterita* Reed, *Clitambonites* (*Kullervo*) *complectans* Wiman var. *albida* Reed, and *Orthis* (*Schizophorella*) *fallax* Salter, and a more complete faunal list has been published by Lamont (1935, p. 300).

We may note the relation of this fauna to that of Tyrone.

Charles Lapworth (1882, p. 618) gave a text-figure of a section of the strata in the Craighead Inlier from Mulloch Hill in the north-east to Auldthorns in the south-east. A starfish bed is indicated at a position high up in the Drummuck Group and approximately on the same horizon as the "Starfish Bed" at Lady Burn almost a mile farther west. No reference is made to this bed in the text and it is shown at a much higher position in the Drummuck Group than that which it actually occupies since there are several hundred feet of the Mudstones between it and the Mulloch Hill Conglomerate.

Lamont (1935, p. 290) in a vertical section gave the true position of this bed in the lower portion of the Drummuck Group and named it "Crinoid Bed". The present writer has never seen any trace of an asteroid in this portion of the group, but there is a hard band exposed which is crowded with poorly preserved fossils among which there are many impressions of crinoid ossicles. These are pentagonal in outline with the angles produced and pointed and rather resemble a small form of starfish. The presence, however, of a central lumen indicates their true nature. Many years ago a number of these were submitted to Dr. W. K. Spencer who categorically declared "not starfish". Lady Burn is the one locality in the Girvan Succession with fossil starfish. There they have been obtained in great abundance both of species and individuals.

(J. L. B.)

DESCRIPTION OF SPECIES

Family Nuculidae

Genus *Ctenodonta* Salter

1. *Ctenodonta collina* sp. nov.

(Plate XIV, fig. 1)

Holotype, BG 11880.[1] Shell subtriangular, tall, rounded below, with small pointed umbo directed forwards ; upper anterior margin nearly straight ; oblique, posterior margin very gently arched ; valves rather strongly convex. Hinge-line bent at rather less than a right-angle at umbo ; hinge-plate wide, crescentic, crossed by a weak transverse groove from umbo to middle of its lower edge ; dentition with posterior series composed of about nine short, stout, strongly bent, transverse teeth successively decreasing in size as they pass forward into a series of 12–14 thin, closely placed, straight, linear teeth ; anterior series of teeth consisting of 5–6 lower, similarly bent, stout, transverse teeth with 4–5 similar thin, straight, upper teeth extending up to the angular bend of the hinge-line beneath the umbo. Anterior muscle-scar well marked.

Remarks.—The only example is an internal cast of a left valve with the umbonal cast and lower part of the shell broken away ; the hinge-line is exposed and perfectly preserved, and the dentition and hinge-plate are well seen. There are two other internal casts (BG 11881) possibly belonging to the same species, but the hinge-line is obscured or missing. From the general internal character we note its resemblance to members of the group *Ctenodonta recurva* Ulrich (1894, p. 580). In shape it is somewhat taller and narrower than any of the group, but most nearly approaches *Ct. obliqua* Hall as figured by Ulrich (1894, p. 604, pl. xlii, fig. 83) ; the dentition most resembles that of *Ct. recurva* Ulrich (1894, p. 602, pl. xlii, fig. 101) and the wide hinge-plate recalls *Ct. compressa* Ulrich (1894, p. 600, pl. xlii, fig. 90). As Ulrich remarks (*op. cit*., p. 580) this group probably deserves generic separation, but Miller's genus *Palaeoconcha* to which he referred a member of it was described as edentulous.

2. *Ctenodonta transversa* (Portlock)

This species is represented in the collection by one right valve (BG 11882), but it does not seem to be identical with any of those figured by Hind (1910, p. 523, pl. iii, figs. 12–14) from various horizons as *Ct.* aff. *transversa*, and we may doubt if they belong to the Tyrone species named by Portlock *Arca transversa* (1843, p. 428, pl. xxxiv, figs. 1–4).

3. *Ctenodonta* cf. *calvini* Ulrich

A shorter more oval left valve (BG 11884) measuring 7·5 mm. in length and 5·5 mm. in height resembles *Ct. calvini* Ulrich (1894, p. 596, pl. xlii, figs. 61–4) in shape, and we may also compare the somewhat variable specimens from the Lorraine formation of New York figured by Ruedemann (1926, p. 14, pl. 1, figs. 13, 14) as *Ct. filistriata* Ulrich.

[1] Registration numbers cited in this paper refer to the Begg Collection.

4. *Ctenodonta* cf. *simulatrix* Ulrich

A complete specimen of a species of *Ctenodonta* (BG 11883), with shell preserved, appears to agree completely in external characters with *Ct. simulatrix* Ulrich (1894, p. 600, pl. xlii, figs. 74, 75 ; Foerste, 1924, p. 135, pl. xvii, figs. 8*a*, *b*) from the Upper Ordovician of Minnesota. The Girvan specimens which Hind figured as *Ct. lingualis* (Phillips) may be identical.

Family Ambonychiidae

Genus *Byssonychia* Ulrich

Byssonychia quarrelensis sp. nov.

(Plate XIV, figs. 3, 4)

Holotype, BG 11885. The well-preserved internal cast of a right valve of a species of *Byssonychia* appears to resemble in some respects the American form named *B. praecursa* Ulrich as figured and defined by Foerste (1924, p. 167, pl. xxviii, figs. 2*a*, *b*), from the Lorraine formation of New York, but differs in certain respects. Some examples of *B. vera* Ulrich, such as the specimen figured by Foerste (1914, p. 134, pl. 1, fig. 15) from the Rogers Gap fauna of Kentucky, bear a considerable resemblance ; and one from the Whetstone Gulf shale figured by Ruedemann (1926, p. 29, pl. 3, fig. 7) may also be compared, for the species varies considerably. *B. elroyi* Hussey (1928, p. 167, pl. ix, fig. 8) from Michigan may be specially compared. The body of our specimen is tall, narrow, subtriangular, and strongly convex ; the umbo is much elevated, prominent, acutely pointed, and slightly incurved. There is a thickened, rounded intramarginal band round the lower margin. A large circular well defined muscle scar is situated close to the posterior margin of the body at about one-third the height of the shell, and a supplementary subquadrate scar of nearly the same size lies in contact above it. The posterior margin describes a broad curve, but the anterior margin is nearly straight and vertical. The posterior wing is large, broad, and flattened, and the post-umbonal hinge-line is long, being about four-fifths of the height of the shell, therein differing from *B. praecursa* ; but this apparent size of the wing may be due to crushing. The precise number of the ribs cannot be determined as they are only shown near the lower part of the anterior margin and round part of the wing, but they seem to be small and to number about forty in all. Height, 34 mm. Width of the wing along the hinge-line about 22 mm. We propose the name of *quarrelensis* for this form.

Family Cyrtodontidae

Genus *Vanuxemia* Billings

1. *Vanuxemia* aff. *sardesoni* Ulrich

(Plate XIV, fig. 2)

There is one imperfect internal cast of a left valve (BG 11886) referrable to the genus *Vanuxemia* which has the cardinal teeth well preserved, and apparently had a subtriangular, gently convex shape with the posterior edge oblique and nearly straight, the lower edge arched, and the anterior

end rounded. The cardinal teeth are three in number, slightly divergent, narrow, and crenulated as in *V. sardesoni* Ulrich (1894, p. 555, pl. xxxviii, fig. 45), and there is a deep subcircular muscle-scar on the hinge-plate below them ; the pallial line is also well marked. Probably this is a new species.

2. *Vanuxemia* cf. *media* Ulrich

The broken and imperfect internal cast (BG 11887) of a more swollen, rounded subquadrate left valve shows the greater part of the rather long, broad, straight, horizontally grooved hinge-area and two strong, stout, subparallel, oblique cardinal teeth above the large deep anterior muscle-area. The teeth are simple and not crenulated. The top of the umbo is broken off and the posterior part of the hinge-line is hidden in matrix. There is a trace of a ridge running down from the umbo towards the posterior lower angle, but all the edge of the valve is missing. We may see a resemblance to several species of *Vanuxemia* figured by Ulrich (1894, pl. xxxviii) rather than any of *Cyrtodonta*, but of them *V. media* Ulrich (figs. 23–6) seems to be the nearest related to it.

Family Modiolopsidae

Genus *Orthodesma* Hall and Whitfield

Orthodesma cf. *approximatum* Foerste

(Plate XIV, fig. 5)

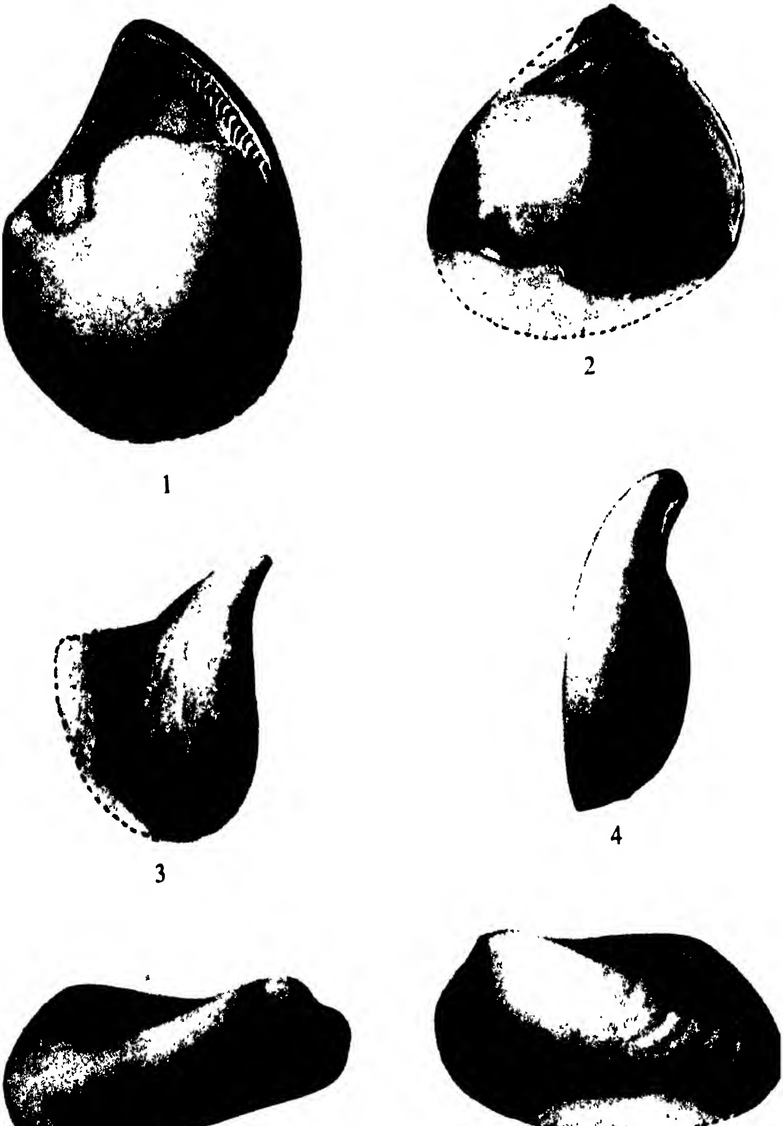
The internal cast of a right valve (BG 11888) in a fair state of preservation, showing the large, circular anterior muscle-scar on the preumbonal projection of the shell may be compared with *Orthodesma approximatum* Foerste (1914, p. 285, pl. 1, fig. 5 ; Stewart, 1920, p. 37, pl. v, fig. 1) and *O. canaliculatum* Ulrich (1894, p. 520, pl. xxxvii, figs. 7–11) from the Upper Ordovician of the U.S.A. and Canada. The smaller length of the first mentioned and the few coarser concentric rugae, as well as the broad umbo and median depression across the valve behind the umbonal ridge which dies out posteriorly agree closely with the figure Stewart gives (*op. cit.*) of an example from the Toronto region. In general characters our specimen also resembles *Orthodonta inornata* Phillip from Marloes Bay (Upper Llandovery) as defined and figured by Salter (*Mem. Geol. Surv.*, ii, pt. 1, p. 362, pl. xix, fig. 3), but is shorter.

Genus *Goniophorina* Isberg

Goniophorina sp.

(Plate XIV, fig. 6)

There is one nearly perfect large swollen strongly carinated left valve (BG 11889) of a shell which seems to resemble the species from the Leptaena Limestone of Sweden described by Isberg (1934, p. 208, t. 27, figs. 3*a*, *b*, 4*a*–*c*, and 5) as *Goniophorina* (*Cosmogoniophorina*) *carinata* sp. nov. and *G. volvens* Isberg (*op. cit.*, p. 205, t. 27, figs. 6*a*, *b*). But the anterior end of our specimen is not well preserved, and the carina is slightly sigmoidal and is more rounded and prominent anteriorly. The triangular area above the carina is strongly depressed and shows traces of 1–2 low narrow indistinct folds. There are a few obscure concentric



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rugae on the strongly convex portion of the valve below the carina, particularly close to and on the carina which they meet at right-angle. The ventral margin of the shell is hidden in matrix; the dorsal margin is straight and there is no sign of a hinge-area or escutcheon. The umbo is apparently anterior or subanterior and rises a little above the hinge-line. The posterior end of the shell is rounded.

Dimensions.—Length, *c.* 46 mm.; height (at umbo) *c.* 25 mm.

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EXPLANATION OF PLATE

FIG. 1.—*Ctenodonta collina* sp. nov. *Holotype*, BG 11880: the internal cast of a left valve, with the hinge-plate and teeth well seen. × 3.

FIG. 2.—*Vanuxemia* aff. *sardesoni.* BG 11886: an imperfect cast of a left valve in which the characters of the cardinal teeth and muscle scar are well seen. × 1½.

FIG. 3.—*Byssonychia quarrelensis* sp. nov. *Holotype*, BG 11885: a well preserved internal cast of a right valve with a large alar area; there is an indication of the ribs of the valve and muscle scars are visible. × 1 approx.

FIG. 4.—The same, a side view showing the curvature of the valve. × 1½.

FIG. 5.—*Orthodesma* cf. *approximatum* Foerste. BG 11888: the internal cast of a right valve showing a large circular anterior muscle scar and a median depression across the valve behind the umbonal ridge. × 1½.

FIG. 6.—*Goniophorina* sp. BG 11889: a nearly perfect large swollen strongly carinated left valve with a few obscure concentric rounded rugae. × 1 approx.

The Order of Crystallization of the Minerals in some Caledonian Plutonic and Hypabyssal Rocks

By S. R. Nockolds

THE determination of the true order of crystallization of minerals in a plutonic intrusion is not an easy matter, but a good deal of information on the subject may be obtained if such an intrusion shows a chilled edge or if there are dykes of corresponding composition. Fortunately, some of the Caledonian plutonic rocks of Western Scotland which we are about to consider do show chilled margins, and there is a series of dyke rocks, loosely termed porphyrites and quartz-porphyries, covering practically the whole range of composition for the rocks on the assumed liquid line of descent.[1] It has been possible to study large collections of these housed in the Geological Department of Manchester University and in the Department of Mineralogy and Petrology, Cambridge.

The chilled phase of the earliest rock lying on the assumed liquid line of descent (pyroxene-mica-diorite) at Garabal Hill, Arrochar, and elsewhere has phenocrysts of plagioclase, augite, rhombic pyroxene, and sometimes olivine. Olivine may be found enclosed in both pyroxenes, and rhombic pyroxene may be enclosed in augite, but the reverse was not encountered. In a highly chilled example from the Carn Chois intrusion there were a few larger phenocrysts of rhombic pyroxene with one or two of plagioclase, and some rather smaller phenocrysts of augite and plagioclase. Biotite is confined to the groundmass in all these rocks, occurring with a second generation of pyroxene and plagioclase and a very little interstitial quartz and potash felspar.

It is equally clear in the normal medium-grained rock that the pyroxenes, plagioclase, and also olivine, if present, began to crystallize early, and that the dark minerals separated out in the order olivine, rhombic pyroxene, augite. Biotite apparently began to crystallize later than all these. It is found as small plates enclosing and moulded upon the pyroxenes and also upon the plagioclase in part; some of it is forming at the expense of the earlier pyroxenes. Quartz and potash felspar began to crystallize later than the other constituents, but it is difficult to say which began first. By analogy with other rocks in the series the quartz would have commenced a little earlier than potash felspar.

The order in which the major constituents commenced to crystallize may be deduced from the above observations to be: olivine (when present); rhombic pyroxene; plagioclase and augite at about the same time; biotite; quartz; and potash felspar. The order in which they ceased to crystallize is somewhat different. Olivine ceased to crystallize at an early stage; rhombic pyroxene, augite, and plagioclase were forming together for a time but, in general rhombic pyroxene ceased crystallizing before augite, and both pyroxenes appear to have ceased before biotite began. There is evidence, however, that plagioclase continued to crystallize

[1] A variation diagram of the Caledonian igneous rocks of Western Scotland, showing the assumed liquid line of descent and the supposed accumulative rocks, s given in Nockolds (1941, 493).

while biotite was forming. Biotite continued until a late stage, a few small flakes being found with the later-formed quartz and potash felspar. Plagioclase seems to have gone on crystallizing, partial outer zones to some of the crystals being associated with the quartz and potash felspar, so that these three minerals were crystallizing together at the end.

Primary hornblende appears in a few of these rocks. It largely replaces and mantles augite, though rhombic pyroxene is also affected to some extent. Hornblende is itself replaced and mantled by biotite and ceased crystallizing soon after biotite began.

In the normal course of events hornblende replaces pyroxene in rocks a little further along the assumed liquid line of descent and these rocks are hornblende-biotite-diorites, a typical example being the so-called xenolithic diorite of Garabal Hill in its uncontaminated state (Nockolds, 1941, 468). This does not show a chilled phase, neither have dykes of corresponding composition been identified with certainty, but it is possible that some of the porphyrites at Portencorkrie (Holgate, 1943, 187) belong here. They are described as carrying phenocrysts of plagioclase and hornblende in a fine-grained groundmass of plagioclase, hornblende, biotite, and a little quartz.

A certain amount of information may, however, be gleaned from the xenolithic diorite itself. Hornblende partly shows good outlines against plagioclase and is partly moulded upon the latter. No complete crystals of amphibole were seen enclosed within plagioclase and it is likely that the felspar started to crystallize first. Biotite largely follows hornblende, mantling and replacing it, while some independent mica is frequently moulded upon the plagioclase crystals. Hornblende may be euhedral with respect to the interstitial quartz and potash felspar. On the other hand biotite is often ragged, as if it had continued to form while quartz and potash felspar were crystallizing.

Passing on to the rocks of higher silica percentage, we come to the various hornblende-biotite-granodiorites, some of which show chilled phases and to which numerous dykes of porphyrite correspond. These porphyrites and chilled phases are found with various degrees of chilling, and it is possible to obtain a considerable amount of information about the crystallization history. The common type of porphyrite or chilled phase has phenocrysts of plagioclase, hornblende, and biotite set in a groundmass of plagioclase, biotite, potash felspar, and quartz. The hornblende phenocrysts are being partially replaced by biotite in many cases, suggesting that hornblende is the earlier of the two minerals. In a highly chilled edge of one of these porphyrites, small phenocrysts of plagioclase and hornblende are present, so plagioclase must have started to crystallize at least as early as hornblende.

It is, however, the groundmasses of these rocks which yield most of interest. In some cases the groundmass is microgranitic and the minerals have the same textural relations to each other as in the plutonic types, though of course on a finer scale. In other cases the groundmass has two generations of crystals. There is an older generation of small plagioclase crystals and little flakes of biotite, and with these there may be a little quartz. Then there is a final residuum consisting of a delicate micrographic intergrowth of quartz and felspar enclosing a few minute

and highly tabular crystals of biotite. This intergrowth is often very fine-grained and the felspar has been rendered turbid, but wherever it is coarse enough and fresh enough to be studied adequately it is found to be an intergrowth of three minerals, namely quartz, plagioclase, and potash felspar. Moreover, the highly platy habit of the mica is a feature wherever such micrographic intergrowths are found, though the size of the flakes varies with the degree of coarseness of the accompanying intergrowth.

It seems reasonable to deduce the following crystallization history from the facts outlined above. Crystallization started with the formation of plagioclase and hornblende, plagioclase probably commencing first. These were followed after a time by biotite. Hornblende then ceased to crystallize, plagioclase and biotite continued together and were joined by quartz. The crystallization of potash felspar followed after a short interval and all four minerals were crystallizing out together. Towards the close of this period biotite ceased crystallizing and the two felspars and quartz continued together until the end. Naturally the composition of the plagioclase changes throughout its crystallization range, but we are concerned at this point simply with the crystallization range of plagioclase as a whole.

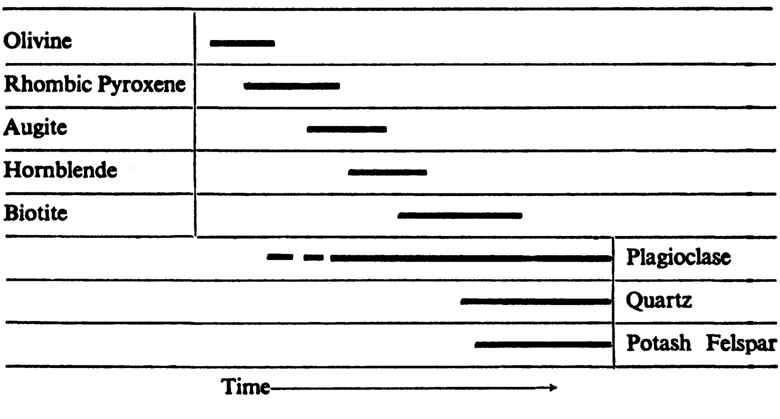
At first sight the typical plutonic granodiorites corresponding with these more quickly cooled rocks do not present much evidence for the continued crystallization of plagioclase. Their texture is granitic and the quartz and potash felspar occur more or less interstitially with respect to the plagioclase crystals as large grains and irregular areas. But these same textural relations may be seen in the microgranitic groundmass of some of the porphyrites and, where these microgranitic porphyrites have chilled edges, such a groundmass may be traced into one of micrographic type. It would seem that the simultaneous crystallization of plagioclase with quartz and felspar is rendered less evident in rocks with granitic or microgranitic texture because much of the plagioclase crystallizing during the formation of quartz and potash felspar is deposited on the already existing plagioclase crystals.

The more acid porphyrites and quartz-porphyries, corresponding to the more acid granodiorites and adamellites, and the chilled margins of these latter when present, show the same general variation in groundmass and the same essential mineralogy as the typical porphyrites, and it is unnecessary to consider them again in detail. The phenocrysts, however, show some features of interest. As the rocks become more acid, that is as they lie further along the assumed liquid line of descent, phenocrysts of hornblende gradually disappear, so that the essential phenocrysts are plagioclase and biotite. In a few cases phenocrysts of quartz make their appearance in addition, but in most rocks potash felspar accompanies the quartz so that all four minerals then feature as phenocrysts. It is important to note that while plagioclase phenocrysts may be accompanied by quartz alone, no example was observed of plagioclase and potash felspar occurring together as phenocrysts without quartz as well. This is further evidence that the order of crystallization deduced from the typical porphyrites is correct, and that there was a short, possibly very short, period when plagioclase and quartz were crystallizing together

before being joined by potash felspar. Moreover, even in the most acid quartz-porphyries, plagioclase always accompanies the quartz and potash felspar phenocrysts.

It should be mentioned that some of the granodiorites and adamellites are porphyritic, with phenocrysts of potash felspar. But in every example examined these phenocrysts enclose smaller crystals of the dark minerals, of plagioclase, and often of quartz. Whatever the conditions leading to this phenocrystal development of potash felspar, it is clear that these do not upset the normal order of crystallization.

If these observations on the crystallization history of the various rock types falling on the assumed liquid line of descent are collected together, the order and duration of crystallization of the various minerals can be indicated as follows :—



The length of the lines is purely diagrammatic, and in pyroxene-bearing rocks where hornblende is absent, the lines representing augite and biotite would have to be extended so that they just overlapped.

The ferromagnesian minerals cease crystallizing out one by one, and all cease to crystallize before the final stage of the crystallization history is reached. Bowen has pointed out that this cannot happen in a eutectic system and that it implies a discontinuous reaction relation between the mineral concerned and the liquid (Bowen, 1928, 59). But, as Bowen remarks, the reaction relation seems to be complex in many cases. For instance, it is not clear from these rocks that rhombic pyroxene reacts with liquid to give augite. These two minerals apparently crystallize out side by side during part of their range, and rhombic pyroxene changes its composition with changes in the composition of the crystallizing augite. Again, hornblende seems to bear a reaction relation to both rhombic and monoclinic pyroxene and to form at the expense of both. It is much to be hoped that in time more experimental evidence will be available for the study of the relations between rhombic pyroxene and augite and between them both and hornblende.

Turning to the light constituents evidence has been adduced to show that plagioclase continues crystallizing until the end, being joined by

quartz and then by potash felspar, both of which also continue to crystallize until the end. Here, therefore, a eutectic relationship of some kind between these three minerals is not excluded, and it will shortly be seen that such a relationship exists.

Brøgger (1890, 82, and 1894) and others have shown that the order of intrusion of a series of plutonic rocks in many cases closely parallels the order of crystallization of the various minerals, and this is one of the lines of evidence leading to the concept of crystallization differentiation. This parallelism is well displayed by the Caledonian plutonic rocks of Western Scotland as is illustrated by the table below :—

Rock Type	Olivine	Rh. pyrox.	Augite	Hornblende	Biotite	Plag.	K-felspar	Quartz.	
Pyroxene-mica-diorites .	(X)	X	X	(X)	X	X	(X)	(X)	Earliest
Augite-mica-diorites . .			X	X	X	X	(X)	(X)	↓
Hornblende-mica-diorites .				X	X	X	(X)	(X)	↓
Granodiorites (early). .				X	X	X	X	X	↓
Granodiorites (late) and Adamellites . . .					X*	X	X	X	↓
Aplites					(X)*	X	X	X	Latest

* A few of these carry muscovite as well. The muscovite-bearing types at any given centre are later than types carrying biotite alone.

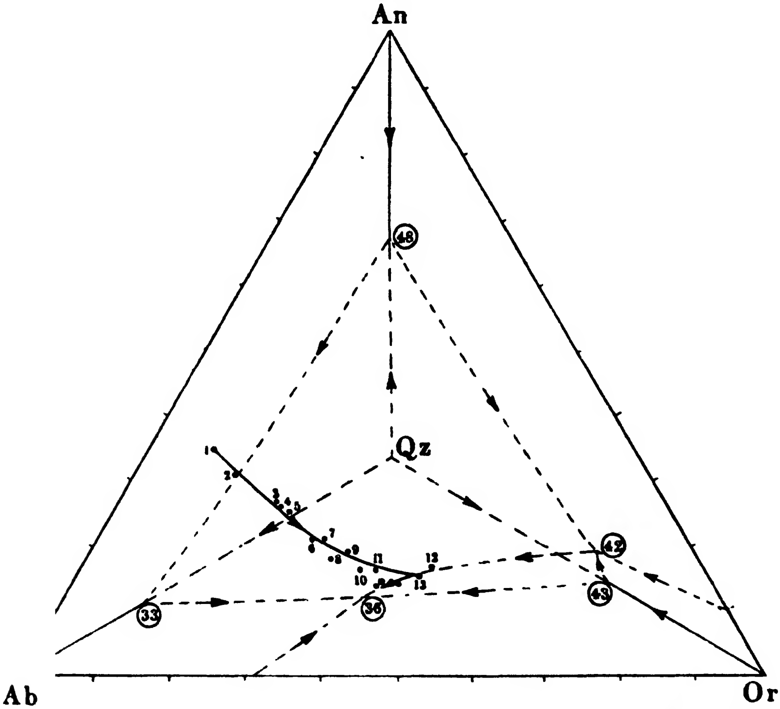
X Indicates an important constituent.

(X) Indicates a minor constituent.

Only the rocks falling on the assumed liquid line of descent are considered in the table, as these are the only ones that should strictly show such a parallelism. But it may be pointed out that the earliest supposed accumulative rocks are the peridotites and pyroxenites (olivine, pyroxene), following them come the gabbros (pyroxene, plagioclase, $\pm$ olivine, $\pm$ hornblende), and finally at a later stage the appinitic types (hornblende, plagioclase, $\pm$ biotite), so that even among these there is the same kind of relation.

The close correlation between the order of intrusion and the deduced order of crystallization suggests that this series of rocks has been formed by processes involving crystal $\rightarrow$ liquid equilibrium, and that the assumed liquid line of descent may be a real liquid line of descent. If this is so then the final products lying at the high silica end of the variation diagram should fall on the plagioclase-potash felspar-quartz cotectic curve. These final products are aplites and related rocks which have been analysed, and, fortunately, sufficient experimental evidence is now available for

constructing, at least approximately, the position of the ternary cotectic curve. Furthermore, knowing the chemical composition of a given rock, its mode, and the chemical composition of the dark minerals which it contains, it is possible to calculate the approximate proportions of orthoclase, albite, anorthite, and quartz, and hence to plot the position of the rock in the diagram of the appropriate four component system. The course of crystallization of these four components can be studied in

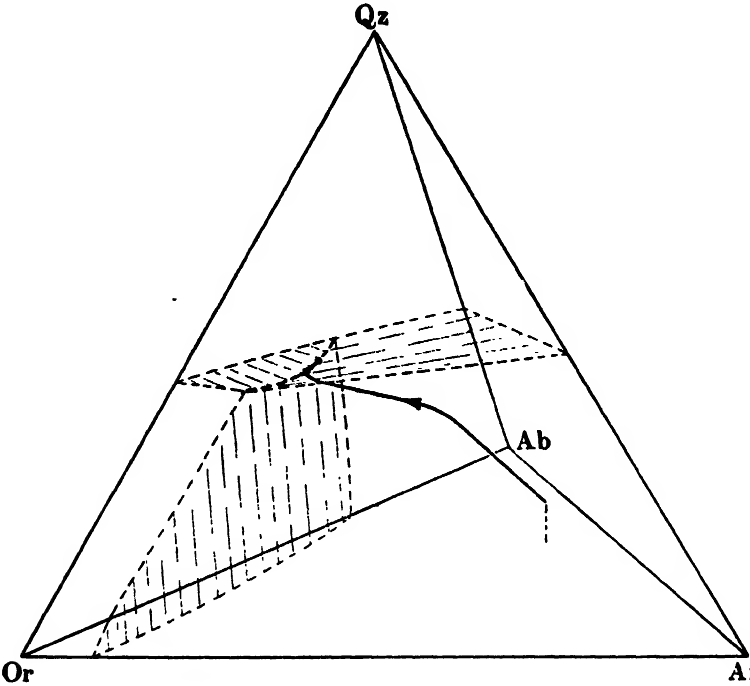


TEXT-FIG. 1—Projection of tetrahedron with apices orthoclase, albite, anorthite, and quartz, showing approximate positions of the plagioclase-quartz and potash felspar-quartz boundary surfaces, and the plagioclase-potash felspar-quartz cotectic curve. The figures in circles indicate the percentages of quartz at the various points. The numbers against the points on the crystallization curve correspond with those given in the table in the text.

this manner, and the crystallization curve should end on the plagioclase-potash felspar-quartz cotectic curve, at a composition corresponding with that of the aplites.

Text-fig. 1 illustrates a vertical projection on the base of the four component system orthoclase-albite-anorthite-quartz, with quartz at the apex of the tetrahedron, while Text-fig. 2 represents an attempt to show the same system in perspective. The data for plotting the approximate positions of the Ab–SiO_2, An–SiO_2, Or–SiO_2 eutectics, the boundary curves between Ab and Or and SiO_2, and the approximate position of

the Or–An–SiO₂ eutectic are taken from various equilibrium diagrams presented by Schairer and Bowen (1935) and Bowen (1937). The exact relations between anorthite and orthoclase are possibly still open to question, but the fields of these two minerals are not likely to be much different from those shown and will have relatively little effect on the position of the ternary cotectic curve at the albite-rich end. It is also possible that



TEXT-FIG. 2.—Perspective diagram of tetrahedron with apices orthoclase, albite, anorthite, and quartz, showing approximate positions of the plagioclase-quartz, potash felspar-quartz, and potash felspar-plagioclase boundary surfaces, and the plagioclase-potash felspar-quartz cotectic curve. The crystallization curve for the Caledonian igneous rocks is represented by the full line beginning in the plagioclase field and ending on the ternary cotectic curve, along which it travels a short distance.

the position of some of the boundary curves such as that between plagioclase and quartz may be offset to some extent in the case of a natural magma owing to the presence of the ferromagnesian constituents. But by the time the aplites are reached such offsetting, if it occurs at all, will be negligible, and the position of the cotectic curve should not be appreciably different from that shown in the diagrams. Orthoclase and albite in the experimentally determined systems appear to form a series of solid solutions with a minimum point. There can be little doubt that, under the lower temperature conditions prevailing in plutonic magmas,

complete solid solution does not occur, and the minimum point in the solid solution curve will be replaced by a eutectic point as shown.

Similarly, the minimum point on the boundary curve between SiO_2 and the Or–Ab solid solutions will be replaced by a ternary eutectic point. The position of the minimum point on the boundary curve must lie somewhere between the compositions Or 26 Ab 38 SiO_2 36, and Or 38·5 Ab 22·5 SiO_2 39 according to the diagram given by Bowen (1937, 12, fig. 8), and we have taken the ternary eutectic point at a composition Or 28 Ab 36 SiO_2 36.

The data used for plotting the course of crystallization shown in the figures are given below :—

No.	Rock Type and Locality	Qz	Or	Ab	An
1	Pyroxene-mica-diorite, Garabal	6	7	54	33
2	" Xenolithic " diorite, Garabal	11	10	51	28
3	Tonalitic granodiorite, Morven-Strontian . .	27	13	41	19
4	Medium granodiorite, Garabal	27	13	43	17
5	Granodiorite, Morven-Strontian	25	16	41	18
6	Porphyritic granodiorite, Garabal . . .	26	20	41	13
7	Outer " granite " (granodiorite), Ben Nevis . .	27	22	39	12
8	Inner " granite " (adamellite), Ben Nevis . .	28	24	40	8
9	" Granite " (adamellite), Morven-Strontian . .	32	23	36	9
10	" Granite " (adamellite), Cairnsmore of Carsphairn	29	29	36	6
11	Meall Odhar " granite " (adamellite), Etive Complex	31	30	34	5
12	Aplite (No. 283), Garabal	36	35	24	5
13	Aplite (No. 561), Garabal	37	34	26	3
14	Quartz-porphyry, Glen Etive	36	32	30	2
15	Aplite (No. 5*a*), Garabal	37	28	32	3
15*a*	Aplite, old quarries, Loch Awe (Etive Complex) .	37	28	32	3
16	Rhyolite, Glen Coe	36	29	33	2

[Chemical analyses of Nos. 1, 2, 4, and 6 will be found in Nockolds (1941, Table VII) together with some data on the composition of the ferromagnesian constituents (Tables II and III) ; analyses of Nos. 3 and 5 are given by Dixon (1934) ; and No. 7 in Anderson (1935, 257) ; of No. 10 in Deer (1935, table opp. p. 72), and its constituent mica in Deer (1937, 496) ; of No. 11 in Anderson (1937, 518) ; and of Nos. 14 and 15 in Bailey and Maufe (1916, 182). An analysis of No. 9 was made available

through the courtesy of the Director, H.M. Geological Survey. The composition of the dark minerals in Nos. 3, 5, 7, 8, and 9 will be found in a forthcoming paper by Nockolds and Mitchell to be published in the *Transactions of the Royal Society of Edinburgh* where, also, analyses of Nos. 8, 12, 13, 15, and 15*a* are given. In the case of rocks 11 to 16 inclusive, the content of dark minerals is so small that it has been ignored.]

The crystallization curve commences in the plagioclase field and rises rapidly towards the plagioclase-quartz boundary surface. The curve then rises more slowly, but probably reaches the plagioclase-quartz boundary surface just before it ends up on the plagioclase-potash felspar-quartz cotectic curve. It then travels a short distance along the cotectic curve towards the ternary eutectic (potash felspar-albite-quartz).

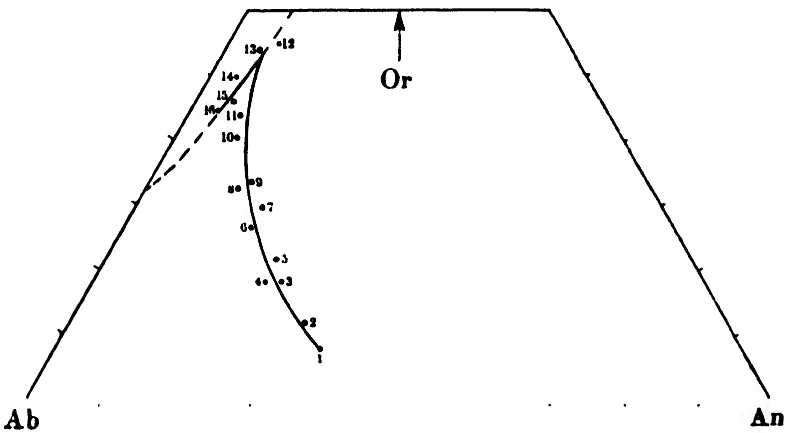
This course of crystallization incidentally confirms the order of crystallization of the light constituents deduced from the mutual relations of the minerals in the rocks. Plagioclase commences first, is then probably joined for a short time by quartz, and finally by potash felspar, all three minerals continuing to crystallize together. It is perhaps unnecessary to emphasize that the crystallization curve constructed applies to the parental magma, the pyroxene-mica-diorite. If a liquid represented by any other point on the curve was separated from the earlier formed crystals, its curve of crystallization would follow a different course (Bowen, 1915, 180). The fact that points representing rocks varying from pyroxene-mica-diorite to aplite all fall on a single crystallization curve is evidence that differentiation took place in depth where a pyroxene-mica-diorite magma was undergoing progressive crystallization, a conclusion already reached from the field relations and petrographic characters of the rocks concerned.

Certain rocks do not fall on the crystallization curve, and this applies more especially to those carrying muscovite as well as biotite. Such rocks fall well off the curve, largely owing to the fact that they are richer in quartz than those falling on the curve. This is the case, for instance, with the muscovite-biotite-adamellite of Moy, Inverness-shire, and with that from the Cairnsmore of Fleet intrusion (Gardiner and Reynolds, 1937), if we assume that the biotite in this has the same composition as that in the Moy rock. It must be confessed that the present work has thrown little light on the conditions inducing the formation of primary muscovite, and further investigation of the behaviour of muscovite-bearing rocks is necessary. But it does seem clear that the formation of muscovite changes the normal course of crystallization.

Vogt has devoted considerable attention to the composition of the granitic " ternary eutectic " (Vogt, 1931) and he has found an average value of about 32 per cent quartz and 68 per cent felspar (in the ratio 40 Or : 60 Ab + An). It will be noticed that the aplites and related rocks lying on, or close to, the ternary cotectic curve here have 4 to 5 per cent more quartz and correspondingly less felspar than Vogt's average, while the Or : Ab + An ratios are 55 : 45, 54 : 46, 50 : 50, 45 : 55, 44 : 56, 44 : 56. Hence the aplites lying nearest to the quartz-potash felspar-albite eutectic show a close approach to the felspar ratio deduced by Vogt, but they remain richer in quartz. The reason for this discrepancy will be considered in a later paper.

It should be noted that Or, Ab. and An in the above discussion refer

to the pure components and not, of course, to the felspars actually present in the rocks. The average *modal* composition (calculated in weight per cent from measurements with an integrating micrometer, ignoring the small quantities of dark minerals) of four of the less differentiated aplites falling on the cotectic curve is: quartz 37, potash felspar 37, plagioclase (about Ab_{90} An_{10}) 26. The average for two of the more differentiated aplites is: quartz 36·5, potash felspar 35·5, plagioclase (about Ab_{93} An_{7}), 28. In the latter case the chemical composition of the separated potash felspar has been determined. The mode calculated from the chemical analyses of these two rocks gives: quartz 37, potash felspar 33, plagioclase 30. This is in good agreement with that derived from measurements with the integrating micrometer.



TEXT-FIG. 3.—Composition of certain Caledonian igneous rocks projected into the system Or : Ab : An. Numbers against the points have the same significance as those in the table in the text. The position of a portion of the cotectic curve between potash felspar and plagioclase is indicated by a broken line.

It is instructive to plot the course of crystallization for the felspars alone, as is done in Text-fig. 3. It has been shown previously that in all the rocks concerned, plagioclase started to crystallize first, except in the aplites where plagioclase and potash felspar crystallized out simultaneously. The points for the aplites and related rocks, then, will be points on the cotectic curve between plagioclase and potash felspar. Knowing the position of the Or : Ab eutectic, we can thus sketch in a portion of this cotectic curve. Its position agrees with that deduced by Bowen (1928, fig. 59, 231) and Doggett (1929, fig. 3, 715), rather than with that deduced by Vogt (1926, fig. 20, 98 ; 1931, 223). The form of the crystallization curve is also interesting. It corresponds with a moderate but not particularly strong degree of fractionation during crystallization (Bowen, 1928, 99).

Pegmatites are not well represented among the end phases of the series of intrusions with which we are dealing but, from a study of such

as are available, it does not appear likely that they will fall on the ternary cotectic curve like the aplites. Most of them are too rich in potash felspar (cf. Vogt, 1931, 70). This may well be due to their richness in volatile constituents so that they no longer conform to laws applicable to more or less dry melts, like the aplites, but behave like watery solutions.

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The Stratigraphy and Structure of the Arenaceous Formation of the Main Range Foothills, F.M.S.

By J. A. Richardson

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I. Introduction

THE Main Range Coulisse (J. B. S., 1923) extends southwards as an arc, convex westwards, from the Patani Province, South Siam, to the Malacca-Johore Interstate Boundary just north of Muar (Bandar Bahru), on the west coast of Malaya. Its length is about 300 miles and its width varies generally from 20 to 40 miles. The present-day range is the granite core of a major orogenic uplift of Cretaceous or possibly of lower Tertiary age from which all the sedimentary cover save a few scattered roof-pendants has been removed by deep sub-aerial denudation.

In Western Malaya—that is in Perak, Selangor, Western Negri Sembilan and Malacca—the Main Range is flanked partly by Permocarboniferous rocks, crystalline limestones, shales, phyllites, schists, and metamorphosed calcareous argillites, and partly by belts of shales, phyllites, fine-grained quartzites and schists which have been assigned on lithological grounds to the Triassic.

East of the Main Range the arrangement and nature of the geological formations is pronouncedly different. Here a well-defined prominent geomorphological feature, the Main Range Foothills, extends southwards from above Kampong Jendera west of Limau Kasturi Halt in South-West Kelantan to an unnamed range of hills north of Bukit Batang Malaka, 1,420 feet, in South-East Negri Sembilan (Text-fig. 1). Its length is 200 miles and its average width about five miles. Its altitude exceeds 2,000 feet in North-West Pahang (Bukit Bertar, 2,234 feet; Bukit Kadjang, 2,421 feet; and Bukit Bruang Berguling, 2,395 feet), and the Foothills taper off and die out farther northwards and southwards. A deeply eroded valley system generally separates the Foothills from the Main Range proper; for example, the Sua-Kerla-Tempoi (Tempol) system in Pahang, and the Serting and Pertang valleys in Eastern Negri Sembilan. But in some places the Foothills lead into the Main Range and the Arenaceous Formation of which they are built rests directly on the granite as, for example, in parts of the Bisek basin and between the Liang Valley and the Tranum-Tras sector, Raub District.

The trough between the Foothills and the Main Range is occupied largely by shale, phyllitic shale, phyllite, mica-schist, mica-quartz-schist, carbonaceous chert, argillites generally metamorphosed, and some arenaceous rocks and quartz-schists in the Jelai Kechil basin. Amphibole-schists (epidote-actinolite-schists containing also zoisite, clinozoisite, quartz, albite, orthoclase, pyrite, magnetite, and occasionally garnet), together with quartz-schists occur in addition to the usual phyllites and

schists in the Telom basin. Epidote-schists, amphibole-schists, tremolite-hornfels, and sheared serpentine are common in the Raub District, and a few small outcrops of serpentine are found in Negri Sembilan.

What of the age and stratigraphical antecedents of this variable suite of rocks ?

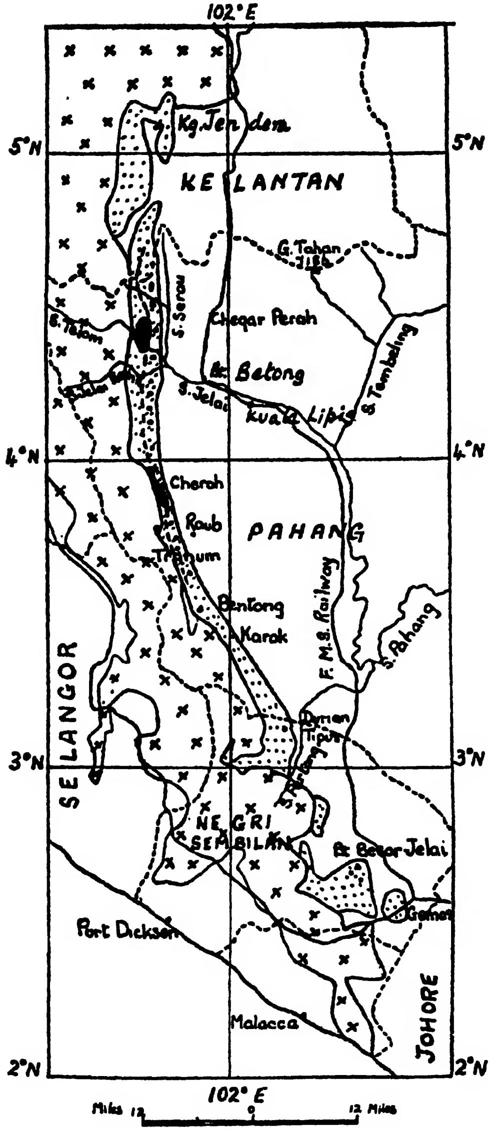
No fossils have been found in any of the rocks of the Foothills and thus their age is not definitely known. The prevalence of amphibole- and epidote-schists which may be metamorphosed calcareous shales and pyroclastic rocks together with intercalated bands of altered rocks of recognizable igneous origin suggests that the strata forming the western zone of the Foothills (that is, flanking the Main Range granite) may be Permo-carboniferous, at least in part, the only one known definitely to include calcareous members (A.R., 1937, paras. 107–112 ; 1938, para. 71 ; J. A. R., 1939). Scrivenor (J. B. S., 1911), who made the first reconnaissance geological sketch map of Ulu Pahang, Willbourn, who began the new survey there based on the 1-inch Topographical Survey Sheets (A.R., 1933, paras. 18–53 ; 1934, paras. 22–37), and the writer (A.R., 1937, paras. 96–112 ; 1938, paras. 51–109 ; 1939, paras. 44–51 ; 1940, para. 39 ; J. A. R., 1939) have considered this possibility.

Eastwards of these valley troughs, or rising eastwards directly from the flanks of the Main Range granite come the Main Range Foothills composed predominantly of arenaceous and pebbly rocks, grits, quartzites, sandstones, quartzite-conglomerates, sandy shales, sandy phyllites, phyllites, shales, schists, and schistose arenaceous and pebbly rocks. They are referred to provisionally as the Arenaceous Formation of the Main Range Foothills, or simply as the Foothills Formation.

The Foothills rise abruptly along their eastern margin from lowlands and uplands rarely higher than 800 feet, built of Permocarboniferous shales, phyllites, and limestones, interstratified with contemporaneous pyroclastic rocks of the Pahang Volcanic Series. These, in turn, are succeeded farther eastwards by a massive development, the greatest in Malaya, of Triassic rocks, lithologically similar to the rocks of the Foothills. They occupy the Lebir Valley in Kelantan and much of the Tembeling and Pahang basins in Central Pahang where they build the Gunong Tahan Range (7,186 feet) Coulisse.

II. The Problems Stated

Over much of their outcrop, and almost wholly in those parts of North-West Pahang mapped by the writer, the rocks of the Foothills Formation strike a little west of north. The dip of the strata is very variable, but although it may locally be steep westwards, or vertical over considerable widths of outcrop in the Telom and Jelai Kechil valleys, it is prevalently steep towards east. The average dip is about 70° or 75° east. The Foothills Formation dips thus below the Permo-carboniferous. Scrivenor has commented upon this fact and has recorded similar examples from the Raub District (J. B. S., 1911). The Foothills Formation has been ascribed everywhere to the Triassic on lithological grounds, and thus it has been assumed that the normal stratigraphical succession has been inverted along the eastern flank of the Main Range granite.



Arenaceous Formation of the Main Range Foothills.

Amphibole Schis Series.

Main Range Granite.

Permocarboniferous and Triassic rocks and several intrusions lying east of the Foothills have not been separated on the map.

NOTE.—West of the heavy broken line drawn near the middle of the Main Range Foothills, lie phyllites, cherts, fine-grained quartz schists, mica schists, and the Amphibole Schist Series which may belong, at least in part, to the Permocarboniferous Formation. All the important quartzite-conglomerates lie east of this line.

TEXT-FIG. 1.—The Main Range Foothills, British Malaya, showing geology and localities.

The problems discussed in this paper are threefold :—

(i) What is the stratigraphical position of the Arenaceous Formation of the Main Range Foothills ?

(ii) What are its structural relationships with the Permocarboniferous and Triassic rocks which lie east of it, and with the rocks which may also be Permocarboniferous along its western margin ?

(iii) Is it conformable or unconformable with the Permocarboniferous Formation ?

III. The Evidence Assembled

A considerable area of the Main Range Foothills has been mapped on the scale of 1½ inches to the mile. The writer has examined the 35-mile tract covered by Topographical Survey Sheets 2 N/7, 2 N/8, 2 N/11, and 2 N/12 ; the following 17 miles south (Sheets 2 N/15 and 2 N/16) were mapped by E. S. Willbourn and H. Service ; 17 miles (Sheet 3 B/4) by Willbourn and the writer, and about 35 miles (Sheets 3 B/7, 3 B/8, 3 B/11, and 3 B/12) by J. B. Alexander. The Foothills in Negri Sembilan were surveyed by Willbourn, who published his map on the scale of 4 miles to an inch (E. S. W., 1922), and both Savage and Willbourn have examined the northern extension of the Foothills in South-West Kelantan (H. E. F. S., 1925). The extent and form of the Foothills are depicted on the Geological Map of Malaya, 1938, and in Text-fig. 1.

(i) *Lithology*

The Foothills in Kelantan consist of shales, phyllites, and quartzites with argillaceous rocks predominating. Between the Interstate Boundary of Kelantan and Pahang and the Pahang Trunk Road they are built largely of medium to coarse-grained quartzites and grits, quartzite-conglomerates, pebbly quartzites, sandy phyllites, and phyllites, schists, schistose quartzites, and schistose conglomerates. The conglomerates consist largely of well-rounded fragments of quartzite and vein quartz together with about 5 per cent of chert, mostly black and carbonaceous, a little jasper, shale, and slaty material, set in a quartzite base. The average diameter of the pebbles is 2 to 3 inches ; the largest boulders exceed 15 inches across. Scrivenor has recorded the presence of chert in the conglomerates of Gunong Tahan (J. B. S., 1907). In the Raub District, notably in Ulu Cheroh, Ulu Chembatu, and Ulu Batu, the Foothills rocks include contorted and sigmoidally deformed quartz-schists which appear to be interstratified with the other rocks of the Formation. In South-West Pahang (Alexander's area) and in Negri Sembilan, medium-grained quartzites and sandstones, shales, and phyllites form most of the Foothills ; conglomerates occur but they are not very abundant. The relationships of these various rocks are further complicated by the lensing out of bands and by isoclinal folding leaning eastwards. Most of the quartz-schists consist of a microcrystalline or very fine-grained schistose mosaic of quartz with partings of metamorphic mica. Recognizable sedimentary grains are generally absent and the writer has not detected their splintered and streaked-out remnants in the rocks. On the other hand, schistose quartzites containing lensed-out

and battered sedimentary grains occur amongst the quartz-schists in the Telom basin and west of Cheroh. The origin of these exceedingly fine-grained quartz-schists is uncertain. They may have been siltstones or shales soaked by siliceous solutions migrant from the adjacent Main Range granite, and intensely sheared more or less contemporaneously. It seems unlikely that they were originally normal sandstones.

The shales, sandy shales, and phyllites of the Foothills Formation mapped by the writer are markedly muscovitic and more or less strongly laminated. The muscovite occurs as ragged flakes as much as 2 mm. in diameter, of detrital origin and distinct from the metamorphic muscovite present in many schists. These rocks appear to have been originally muscovitic siltstones and mudstones. Scrivenor (J. B. S., 1911, p. 40) has recorded that the schists and quartzites of Gunong Tahan are also muscovite-rich.

The argillites and their metamorphosed equivalents, and also many sandy rocks of the Foothills Formation, are commonly rusty purple-brown or deep reddish-purple, and this is particularly noticeable in weathered specimens. Permocarboniferous argillites, by contrast, are never muscovitic unless the mica has been produced by metamorphism. Unweathered, they are coloured in various shades of grey and black ; they weather in pale greys and buffs. Bleaching of black carbonaceous types to bone-white is very common.

All the Foothills rocks were laid down in a shallow-water neritic environment with the probable exception of the coarser pebble- and boulder-conglomerates which may represent a littoral facies.

The lithology of the Foothills Formation closely resembles that of the Triassic Formation of Pahang, Kedah, and Gunong Semanggol in Perak, where medium-grained quartzites and quartzite-conglomerates are also strongly represented.

The Foothills rocks are strikingly different from most strata known to be of Permocarboniferous age, for, whereas the former are essentially arenaceous, the latter are argillaceous and calcareous. Another difference is that whereas contemporaneous pyroclastic rocks and lavas of the Pahang Volcanic Series are commonly intercalated with the Permocarboniferous and Triassic Formations in Kelantan and in parts of Pahang, they are absent from the Main Range Foothills. Volcanic rocks occur but rarely in the Trias of the Tembeling valley also.

Igneous material, mostly grains and groundmass fines, is present in small amounts in the arenaceous and pebbly rocks of the Foothills, but so far as the author's observations go pebbles of rocks belonging undoubtedly to the Pahang Volcanic Series have not yet been discovered in them. This igneous material is probably older than the Foothills Formation.

(ii) *Palaeontology*

The Foothills rocks have yielded no fossils anywhere within their outcrop, although some of the finer grained sandy types and the shales may be fossiliferous. The fact that most of them have suffered some degree of metamorphism, in some cases sufficiently intense to convert even quartzite-conglomerate into pebbly schist and quartzite into massive

schists which have obviously undergone plastic deformation, militates against the survival in them of fossils, assuming that they were ever present. There is no palaeontological evidence relating to their age.

(iii) *Structure and Stratigraphy of the Main Range Foothills*

The structure of the Foothills is complex between the Kelantan border and the Pahang Trunk Road. Over a width of outcrop of as much as two miles in the Telom and Jelai Kechil basins, and in parts of the Raub District, the Foothills rocks maintain an almost permanent vertical dip. Locally very acute folds occur, of which the limbs dip 80° $\wedge$ 80°, 85° $\wedge$ 85°, 90° $\wedge$ 80°, etc. Often they are isoclinal and inclined steeply eastwards. Minor furrows, contortions, and sigmoidal flexures are common. Along the eastern margin of the Foothills, however, these rocks usually dip at about 70° to 80° beneath the Permocarboniferous Formation, but here also they may locally be vertical.

In the 35-mile tract lying south of Kelantan the author mapped a divergence of regional strike varying from 10° to 20° between the trend of the Permocarboniferous Formation along the eastern margin of the Foothills and that of the Foothills Formation itself. Taken at its face value this difference of strike suggests that a small angular unconformity exists between the two formations, but this evidence is inconclusive because a study of the regional trend-lines and of the arrangement of the tectonic axes in North-West Pahang suggests that the Main Range Foothills acted as a massive buttress-block in opposition to regional pressures operating from east or south-east. The Permocarboniferous rocks appear to have been moulded in curvate bands, exhibiting some degree of drag, along the eastern margin of the Foothills. Their degree of metamorphism increases and their structure becomes more complex along this eastern margin.

Scrivenor (unpublished field notes) has stated that the lie of the conglomerate on the conglomerate hill at Bentong (Gunong Raka) suggests that it is unconformable on the Chert Series (cherts, radiolarian varieties, shales, and phyllites, etc. ; (J. B. S., 1931)) which lies farther west.

The Selinsing Gold Mine lies north of parallel 4° 15′ N. and east of the Main Range Foothills. The ore-bodies are located along an east-dipping zone of strike-faulting in Permocarboniferous phyllite, calcareous phyllite and limestone. Cross-cuts east from the 200-foot level in the mine passed first through Permocarboniferous rocks and thence into quartzite and conglomerate belonging to the Arenaceous Formation. The Arenaceous Formation dips eastwards below the Permocarboniferous at Selinsing, and this in turn is succeeded still farther eastwards by quartzites and conglomerates also dipping east. It appears that the Foothills Formation may here be folded into a slightly overturned syncline with a core of Permocarboniferous.

Massive limestone associated with phyllite crops out in the Sungei Telom almost in the middle of the Foothills. Together with phyllites and shales adjacent, the limestone, presumably of Permocarboniferous age, forms a long narrow belt of lowland enclosed by quartzites and conglomerates of the Foothills Formation. The limestone and argillites appear to be infolded into the coarser sediments.

The Foothills Formation was mapped originally as Triassic because both formations are predominately arenaceous and pebbly, and because no arenaceous rocks were believed to occur among the argillaceous and calcareous strata of the Permocarboniferous. Thin bands, usually not more than a few feet wide, of a characteristic and distinctive quartzite, are intercalated with Permocarboniferous limestone and shale on Topographical Sheets 2 N/8 and 2 N/12. This rock, drab grey-brown, hard, compact, indurated, and fine-grained, consists of highly angular fragments of water-clear quartz, together with small amounts of pyroclastic material, mostly rhyolitic, and a few fragments of orthoclase, cemented in a base of silty clay containing minute quartz splinters. It is limonitic and may contain a little dispersed carbon dust. The strongly angular form of its component fragments distinguishes it from the normal grits and quartzites of the Foothills in which the grains are mostly well rounded.

Service (in verbal discussions with the writer) suggested that the geological structure around Kuala Lipis can most easily be explained by assuming that thin limestones occur contemporaneously intercalated with Triassic rocks and that sandy beds are interstratified with Permocarboniferous shales and limestones. The probability of this being a correct interpretation is increased by the fact that the structures mapped in this area are on the whole fairly simple. Dr. F. T. Ingham, revising some of the earlier mapping of the Kinta Valley, has included fine-grained arenaceous rocks with the Permocarboniferous Formation, and E. S. Willbourn has made similar adjustments to Savage's map of the Sungei Siput Sheet, 2 N/1 (H. E. F. S., 1937).

There has been a tendency, therefore, since about 1932, to deviate from the earlier view that all calcareous rocks are Permocarboniferous and all arenaceous rocks Triassic. Scrivenor, commenting upon this fact in a letter to the writer, stated his opinion thus : "I think it would be better to wait for palaeontological evidence, whether lithological mapping produces problems in mapping or not."

The geological map of Malaya reveals some strange associations of Permocarboniferous limestone and shale with rocks shown as Triassic (e.g. in Perlis, Kedah, Ulu Perak, Selangor, Ulu Tembeling, Johore, etc.) which are difficult to explain on stratigraphical grounds alone, and which seem to necessitate the intervention of complicated tectonics. However, Willbourn emphasizes in a written communication to the writer, that there is proof that such complicated structures actually exist in one locality 6¾ miles north of Raub and 2½ miles east of the eastern margin of the Foothills Formation. This locality lies in the Sungei Taba, a tributary of the Sungei Semantan (Sheet 3/B4), and here a small very narrow strip of fossiliferous Triassic rocks has been infolded into the Permocarboniferous. Two thin bands of fossiliferous pink marly shale, separated by 20 feet of unfossiliferous dark green gritty shale, are entirely enclosed by Permocarboniferous phyllite (L. R. C., 1936 ; J. A. R., 1939, p. 23).

IV. Summary

The evidence relating to the problems raised by the Arenaceous Formation of the Main Range Foothills may be summarized thus :—

(i) The Foothills are built as a rule of predominantly arenaceous

sediments ; belts of quartzite-conglomerate occur and argillaceous types generally are interspersed with the coarser grained rocks.

(ii) Lithological variations northwards and southwards along the strike of the Formation, and eastwards and westwards through its stratigraphical succession are very great.

(iii) No fossils have been found anywhere in these rocks and their age is consequently not definitely known.

(iv) The Foothills have obviously been the site of orogenic pressures and metamorphism, and they appear to have formed a buttress against which the Permocarboniferous rocks have been moulded by forces from east-south-east or east.

(v) There is a persistent difference of 10° to 20° between the general strike of the Foothills Formation and that of the Permocarboniferous Formation along the eastern margin of the Foothills in the 35-mile tract examined by the writer. This fact cannot be accepted as proof that an angular unconformity exists because structural complexities dependent upon (iv) above can also afford a satisfactory explanation of this divergence of strike.

(vi) Scrivenor has mapped the Foothills Formation as Triassic, so that its easterly dip below the Permocarboniferous must, on this hypothesis, be due to overfolding.

(vii) Between the western margin of the Foothills and the Main Range granite, occur rocks, many of them strongly metamorphosed, which may originally have been calcareous shales, pyroclasts, and impure limestones, presumed, on lithological grounds, to be of Permocarboniferous age. Their alteration has been so profound that no transitional types have been discovered between thorough-going amphibole- and epidote-schists and the presumed parental calcareous sediments. Metamorphosed argillaceous and arenaceous rocks accompany them.

V. Structure and Stratigraphy of the Arenaceous Formation of the Main Range Foothills in Relation to that of Malaya as a Whole

Any attempt to solve the problems relating to the structure and stratigraphy of the Foothills Formation must be made in relation to British Malaya as a whole.

If, following Scrivenor, the stratigraphical succession be subdivided into two formations, the Permocarboniferous and the Triassic, then their distribution as shown on the geological map can be explained as the vagaries of form produced by erosion operating upon two strongly infolded groups invaded by a huge mass of magma, predominantly granitic, which seems to have stoped its way through them and to have engulfed considerable volumes of sediments in so doing.

The structure of the broad intramontane trough between the Main Range granite and the Gunong Tahan Range is known in some detail. One arm of a large syncline follows the Sungei Serau Valley between the Main Range Foothills and the Chegar Perah–Pulai intrusion, and the other branch follows the valley of the Sungei Tanum between this granitic intrusion and the Gunong Tahan Range. The Chegar Perah–Pulai intrusion itself lies along an important compound uplift, and the Bukit Mangi and

Bukit Damar granites farther east are aligned along simpler domed uplifts.

The problem is to fit the stratigraphy and structure of the Main Range Foothills into a tectonic pattern known in some detail for the country immediately east and west of them and to make it conform with the generalized structure of the Gunong Tahan Range and the Main Range Coulisses of which much less is known.

The structure of Central Malaya as depicted in Section I (Text-fig. 2) has been drawn to accord with the assumption that the Arenaceous Formation of the Main Range Foothills is Triassic, and thus more or less contemporaneous with the rocks of the Gunong Tahan Range. If this assumption be true then the Main Range Foothills occupy a syncline or synclinorium overturned slightly and dipping isoclinally eastwards at about 70°. The quartz-schists, schistose fine-grained arenaceous rocks and phyllites which flank parts of the Main Range granite in the Telom and Jelai Kechil basins and in the Raub District may also be Triassic and the equivalent of the marginal varieties (mainly sandy and argillaceous rocks) that flank the Main Range Foothills along their eastern margin. The westerly anticlinal continuation of such a structure might well impinge upon and include the few roof-pendants of very fine-grained mica-quartz-schist, quartz-schist and phyllite in the Sungei Bertam Valley, Cameron's Highlands, in Ulu Terla, and at Gunong Korbu, 7,160 feet. These roof-pendants were mapped as Triassic by Scrivenor (J. B. S., 1919). Altered calcareous rocks associated with the quartz-schists and phyllites at Renglet, in the Sungei Habu Valley and on the Cameron's Highlands Road shown as Triassic on the 1930 geological map of Malaya are now considered to be Permocarboniferous and are depicted thus on the 1938 geological map.

The generalized succession in the Main Range Foothills area would now read :—

(2) Triassic ; Arenaceous Formation of the Main Range Foothills.

B. Quartzite-conglomerate, grit, and quartzite.

A. Quartzite, shale, and phyllite and very fine-grained sandy rocks.

(1) Permocarboniferous ; limestone, shale, and volcanic rocks.

Such a succession might be interpreted as indicating that the sea in which the Permocarboniferous shales, limestones, and contemporaneous pyroclastic rocks were deposited became rather suddenly shallower, thus giving rise to conditions whereunder first, sands and muds, and later pebble and boulder beds were accumulated. This interpretation suggests that the conglomerates, many of them coarse boulder-conglomerates which form the core of the Foothills, are a top phase of the sedimentation of the old Malayan geosyncline. In other words the development of sandy beds along their eastern margin might be construed as marking a rather abrupt passage without a definite unconformity from the Permocarboniferous to the very coarse beds above.

Umbgrove (J. H. F. U., 1938, p. 7) has stated that the Permian merges gradually into Triassic sediments in Central Sumatra, that a similar relationship probably holds for Eastern Celebes, Timor, and the

Padangsche Bovenlanden of West Sumatra, and that Scrivenor considers it possible in Malaya also.

Scrivenor has stated that there is overfolding in the Gunong Tahan Range in Kelantan and Pahang. The Triassic age of part of the Gunong Tahan Range in Kelantan is proved by the presence of *Daonella* or *Halobia*. Part may be Permian, but none of these rocks can be older than the Carboniferous rocks farther west. Westerly or south-westerly dips are common on Gunong Tahan and Larong, and in the Sungei Tahan. If these dips be continued westwards the Triassic rocks will pass below the Permocarboniferous ; overfolding must have occurred here (J. B. S., 1931, p. 104). In addition Zwierzycki has stated that the Triassic and older rocks of Sumatra have been overfolded north-eastwards, and this evidence accords with Scrivenor's observations in British Malaya (J. B. S., 1931, p. 108).

If, however, it be assumed that the Arenaceous Formation of the Main Range Foothills is older than the adjacent Permocarboniferous rocks, then the geological structure must approximate to the pattern indicated in Section 2 (Text-fig. 2), and the succession will then be :—

(3) Triassic of the Gunong Tahan Range and the Tembeling basin.
(2) Permocarboniferous.
(1) Arenaceous Formation of the Main Range Foothills.
  B. Quartzite, shale, phyllite, and very fine-grained sandy rocks.
  A. Quartzite-conglomerate, quartzite, and grit.

This interpretation of the structure implies that an early shallow-water phase obtained while the coarse-grained sediments of the Arenaceous Formation were being accumulated ; that the sea deepened towards the close of this period and led on thus to the conditions of sedimentation under which the Permocarboniferous Formation was laid down. The sea shallowed again during the succeeding Triassic period and the geosyncline became more or less completely silted up at its close. Mesozoic rocks younger than Triassic are unknown in Malaya.

The author suggests that the structure may approximate to that depicted in Section 2 (Text-fig. 2). It is thought that the stratigraphical formations, three according to Service, Alexander, and myself, although intensely folded, yet retain a fundamental simplicity of relationship in that the major division lie pancake-fashion one upon the other.

The Permocarboniferous Formation in North-West Pahang, over a width of outcrop of some 20–25 miles lying between the Foothills and the Gunong Tahan Range, has been subdivided into eight lithological groups. The few fossils discovered were too poorly preserved to afford any data concerning the relative age of the groups and the lithology of these subdivisions is very variable. These facts notwithstanding, it is curious that not one of the groups that occurs near the eastern margin of the Foothills has been definitely recognized in the eastern portion of the broad trough that separates them from the Gunong Tahan Range. The only exception to this generalization may be afforded by the massive limestones which occur towards the middle of the Permocarboniferous Formation ; mapping suggests that there are two limestone groups, but there may actually be only one duplicated by folding.

The idea of intensely plicated layers (the writer mapped at least twenty large parallel tectonic axes in addition to a considerable number of minor folds within an outcrop width of some 12 miles) related spatially to each other so that the whole sandwich of slabs dips more or less gradually eastwards and rises in anticlinorial humps over intervening tectonic uplifts, seems to afford an explanation of the structure of North-West Pahang.

According to this interpretation of the structure, then, the Arenaceous Formation of the Main Range Foothills should underlie the argillaceous, calcareous, and pyroclastic rocks of the Permocarboniferous Formation.

In 1939 F. H. Fitch discovered brachiopods, trilobites, plant remains, crinoid ossicles, bryozoa, and one lamellibranch in a bed of shale 1 foot thick, lying between two quartzite bands in the Sungei Terapai, Anak Kuantan, East Pahang. The strata of this area were mapped originally as Triassic in the absence of palaeontological evidence to the contrary and because arenaceous rocks were present. The fossils identified by Dr. Helen Muir-Wood and others prove that the rocks containing them are Carboniferous of Viséan age.

Fossils obtained from Bukit Charas, Bukit Sagu, and Bukit Tinggik, near Kuantan, some years ago were also described by Dr. Stanley Smith as Viséan. Amongst them, *Recticulina imbricata* and *Pugnax pugnas*, range from C2 to D2, but the remainder are characteristic of the Dibunophyllum zone.

It is possible that the shales of the Sungei Terapai are older than the limestones of the three hills above mentioned.

Scrivenor and Willbourn have mapped feldspathic, calcareous quartzites, and shales which occur conformably beneath fossiliferous limestone in the Langkawi Islands (J. B. S. and E. S. W., 1923), Perlis and Kedah (E. S. W., 1926). All these rocks are Permocarboniferous. They are unknown elsewhere in British Malaya. Scrivenor has stated that they do not resemble the Foothills rocks and that he has found no coarse conglomerate amongst them. He considers them to be an extension of the Mergui Series of Lower Burma.

There exist, thus, below the Permocarboniferous limestone, arenaceous and argillaceous rocks which have yielded fossils proving that they are older than this limestone.

Can the Arenaceous Formation of the Main Range Foothills be considered as analogous to, although not necessarily contemporaneous with, the pre-limestone and shale rocks in East Pahang, Perlis, Kedah, and the Langkawi Islands ? There is no proof either *pro* or *contra*, yet the suggested structural arrangement of North-West Pahang gives a fairly simple pattern based on this assumption.

In conclusion it must be stressed :—

1. That the lithology of the Triassic Formation and of the Arenaceous Formation of the Main Range Foothills is extremely variable and that the pattern of these variations is not well known. As a result it is thought unsafe to assume that the close lithological similarity of these two formations implies their being identical one with the other.

2. That no fossils have been found anywhere in the Main Range

Foothills and none also in those rocks mapped, again solely on lithological grounds, as Triassic in Malacca, Selangor, and Perak as far north as Kuala Kangsar. Nothing definite is known of their age. Structural complications such as those discussed in North-West Pahang may also occur in West Malaya with the result that some of these western arenaceous strata may not necessarily be Triassic, but older than Permocarboniferous.

3. The structure of the Main Range Foothills and their relationship to the Permocarboniferous and Triassic Formations therefore cannot be solved in detail at present. In addition it has not always been possible to decide which way up a succession should be read, and it is thus difficult to decide if two or three stratigraphical formations are present.

As a result the problems discussed in this paper cannot definitely be elucidated. It appears probable that an unconformity exists between the Arenaceous Formation of the Main Range Foothills and the Permocarboniferous rocks, but no direct proof can be adduced. The Foothills Formation seems on structural grounds to be older than Permocarboniferous, and the occurrence elsewhere in Malaya of sandy and shaly rocks older than the Permocarboniferous limestone affords some slight support to this view.

VI. Acknowledgments

The writer thanks Mr. J. B. Scrivenor and Mr. E. S. Willbourn for reading the paper and for helpful and constructive criticisms thereon, the Director of Military Survey who supplied maps of Malaya, and Mr. W. N. Edwards, British Museum (Natural History), who allowed him to read Dr. Helen Muir-Wood's report, " Malayan Lower Carboniferous Fossils, and their bearing on the Viséan Palaeogeography of Asia," prior to its publication by the Museum.

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The Geological Structure of Wirral

By David E. Owen (Keeper of Geology, Liverpool Museums)

1. Introduction

THE rocks of the Wirral Peninsula in Cheshire were originally described by John Cunningham in 1839, as three series, two moderately resistant to the east and the west, separated by a central region of soft sandstones and marls, dipping uniformly eastwards. G. H. Morton noted this in 1872, as a good description of the strata, ignoring faults, and pointed out the significance of the faulting. Since that date the faults have been mapped in great detail, and most of the structural features ascribed to them. G. H. Morton was particularly accurate with his mapping of faults both in Liverpool (1899), and in Storeton (G. H. Morton, 1883, and H. C. Beasley, 1914). The folding finds its first mention in the Geological Survey Memoir of 1923, two elongated synclines being mentioned, one from Heswall northwards and the other from Storeton to Prenton. The former is undoubtedly an important synclinal feature, but the latter is made up of two folds, a north to south anticline at Storeton, and an east to west syncline at Prenton. The only other records of folding in Wirral are by F. T. Maidwell in 1920 and by T. A. Jones in 1937, who mention an anticline at Ellesmere Port. This paper is therefore chiefly devoted to a description of the folding in the area.

2. Field Observations

The faulting is extremely easy to map along the junction of the hard Lower Keuper and the soft Upper Mottled Bunter Sandstones. The former beds have been extensively quarried, and many faults are visible in section. It is probable that this is the chief reason why faults have received so much more notice than folds. The faults are often accompanied by slickensiding and similar features, and this has attracted much local attention.

Owing to the considerable current-bedding, often accompanied by large-scale slumping, which is so marked a feature in Triassic sandstones, it is extremely difficult to ascertain the true direction or amount of dip in small exposures. The dip of the current-bedding may be oblique to that of the true bedding or even diametrically opposite to it. In slumped beds it may exceed the vertical, though the true dip is seldom greater than 12 degrees. Thus the fold structures in the past have tended to be ignored, the dips being treated with great reserve.

Small scale folding is often simulated by the faulting. When the dip of the beds is in the opposite direction to the hade of the fault, a small syncline may appear on the downthrow side and a small anticline on the upthrow (R. C. B. Jones, etc., 1938). These folds are normally narrow, the width being in the order of one hundred yards. The dip of the strata at the north-east point of Wirral is probably influenced by such a structure.

The true dip may best be observed along such datum planes as the marl beds in the Keuper Sandstones and the Bunter Pebble Beds and the hard band in the Upper Mottled Sandstones. It is also measurable in beds of sandstone unaffected by current-bedding. This has been recorded over the whole of the Wirral Peninsula. The fold structures are also brought out by the outcrop of the base of the Bunter Pebble Beds and of the Lower Keuper Sandstones.

The two sets of observations, the dip of the strata and the lines of outcrop of the more resistant horizons, combine to show clearly the fold structure of Wirral. They are recorded in the accompanying sketch map (Text-fig. 1). Faults, except the boundary fault, are omitted. The boundary fault, separating Coal Measures from Trias, appears to have a marked effect on the fold structures, and is therefore included.

3. The Folds

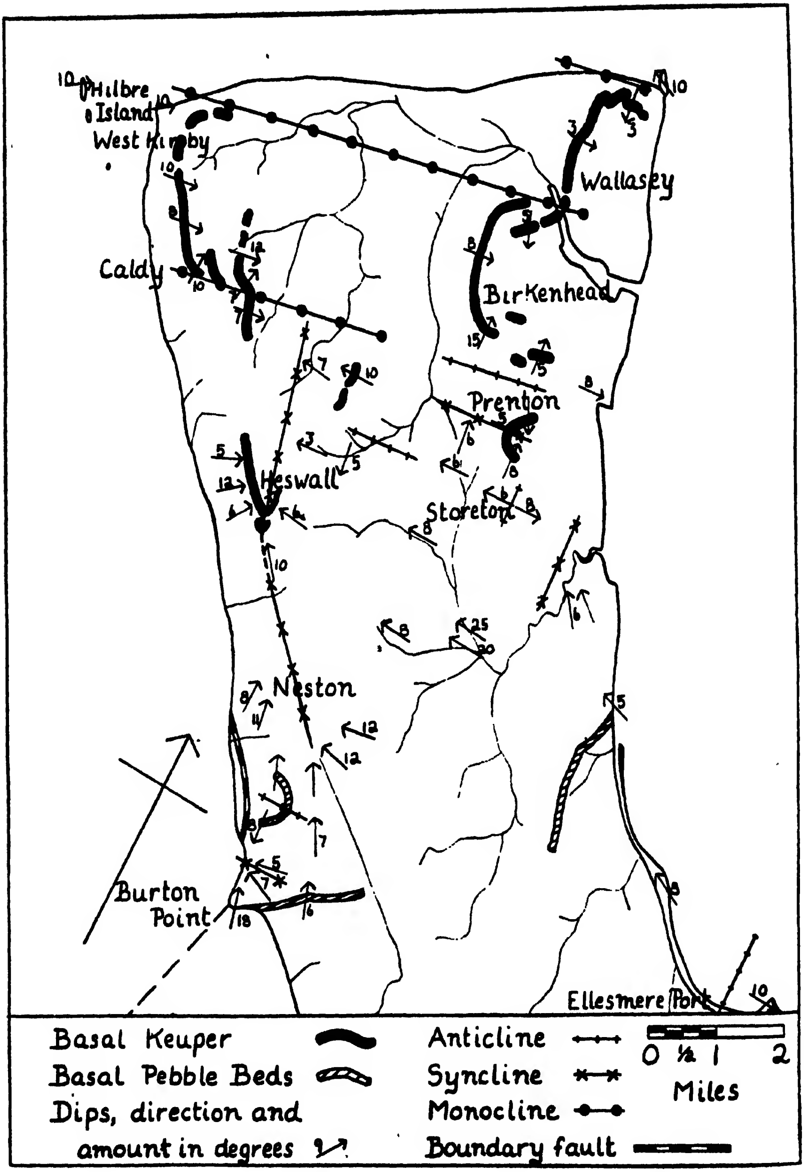
The folds fall readily into two categories, those with axes running from north to south, and those trending from east to west.

The folds with north to south axes include two synclines and two anticlines. The most westerly is the Heswall syncline. This is responsible for the highest ground in Wirral—359 feet above O.D. in Heswall Village, where the hard Keuper Basement Beds dip inwards from the west, the south, and the east. The fold is traceable northwards for two and a half miles, but it appears to die out as it reaches the east to west monocline of Caldy. South of Heswall, the Trias is obscured by drift, but three miles further to the south, around Neston, the synclinal structure is again shown by the dips. The axis has curved to the south-east, and is parallel to the Coal Measures boundary fault.

The Storeton anticline has been known for many years, and is figured but not described by G. H. Morton (1863). It is well exposed in the many quarries of Storeton Hill (famous for the Keuper "Footprint Beds") and in east to west road sections. The Ellesmere Port anticline was mentioned by F. T. Maidwell (1920), and later by T. A. Jones (1937), from information from borings. Both folds are alike in that the *youngest* beds are exposed in the cores, this strange feature being brought about by faulting. Thus, the cores of the anticlines are so cracked by faults, that the Keuper marls are visible at Storeton and the Upper Mottled Sandstones are found in borings at Ellesmere Port. The Storeton anticline is terminated to the north by the east-to-west Prenton syncline. It quickly pitches to the south. The extent of the Ellesmere Port anticline is not known, as it is drift covered to the south and is buried beneath the wide Mersey Estuary to the north. A small syncline must lie approximately one mile to the east of the Storeton anticline to account for the dip and the outcrop of the rocks.

The east-to-west folds are considerably developed in North Wirral, and they have had a marked effect upon the scenery. They throw forward or backward the main Keuper escarpment and form breaks in the otherwise continuous lines of hills.

The most northerly fold is a monocline at the extreme north of the Wallasey Peninsula, and is shown by the northerly swing of the dip and of the escarpment. To the south of Wallasey a second monocline appears,



TEXT FIG. 1. Structural Sketch-map of Wirral Peninsula.

demonstrated by both dips and outcrops. It has been utilized by the main river system of North Wirral to breach the Keuper Hills. Along the western seaboard, the Keuper escarpment does not extend so far north, and rocks are covered deeply by drift. Bunter Pebble Beds reappear at the north-west point of Wirral, though from the strike of the Keuper rocks at West Kirby, Upper Mottled Sandstones are to be expected. The occurrence of pebbly sandstones low down in the Pebble Bed series is no doubt due to the monocline having a similar effect upon the Keuper escarpment as at Wallasey. The dips at this point and at Hilbre Island are to the north-east. This is probably due to the proximity of the Coal Measures boundary fault which lies a short distance to the west.

The third monocline is a further two and a half miles to the south in North-West Wirral, and is visible round Caldy. Dips and outcrops demonstrate its presence clearly. The Keuper escarpment is repeated by north and south faults, but the swing of the outcrop due to the monocline is visible in every repetition. Further to the east, however, it has been replaced by an anticline and a syncline at Prenton, the former occupied by an important wind gap. The syncline once more forms the hill, in this case the most elevated ground in east Wirral. A further small anticline or monocline appears to lie about two miles to the south-west of Prenton, midway between that locality and Heswall. It is not easy to place definitely as it is deeply drift covered.

The remaining two east-and-west folds occur between Burton Point and Neston. Their presence is proved by both dip and outcrop, but they are of very limited extent. They are terminated westwards by the Coal Measures boundary fault, and they die out eastwards. The syncline shows the pitch particularly well, as the rocks are exposed in railway cuttings on either side of Burton Point station. The dips can be seen to swing from north to west and on to south-west.

4. Relation of Folds to Faults

Like the fold system, the faults can be divided roughly into those which run from north to south and those with an east to west trend. The latter have been shown in one or two places to be subsidiary to the former. For instance, at Caldy Grange, small east-and-west faults run out from a major north-and-south dislocation and appear to owe their presence to differential movements along the main fault (H. C. Beasley and J. Lomas, 1892).

The main Coal Measures boundary fault belongs to a different category. It is of much greater throw than any other Wirral fault (cutting out the entire Lower Mottled Sandstone group—over 1,200 feet—in places), and it runs from north-west to south-east. It is not seen in section at the surface owing to drift and its existence is inferred over much of its length. It has been met, however, in the old Wirral Collieries south of Neston. Its presence seems to have altered the direction of the axis of the Heswall syncline which bends to the south-east. Several of the normal Wirral faults in that area make a similar change in direction.

A fault with a north-north-west and south-south-east trend in North-East Wirral has been shown to be cut and displaced by a north-to-south fault (J. Lomas and A. R. Dwerryhouse, 1893). It is therefore possible

that faults of this trend are of pre-Triassic origin, and that post-Triassic movements taking place along them predated the more general north-to-south and east-to-west faults.

The two folds near Burton Point are terminated by the Coal Measures boundary fault. The only other fault across which the folds do not appear to run is one which trends southwards from the north-eastern point of Wirral, inside the coasts of Wallasey and of Birkenhead (known as the Seacombe fault by the Geological Survey). The throw of this fault is between 600 and 1,000 feet, and it is therefore possible that resistant rocks are thrown near enough to the surface on the east side to have precluded folding. No other fault in Wirral has so large a throw.

In general the folds and faults are intimately connected. For instance, the faults are the most numerous in the cores of the north-and-south anticlines of Storeton and Ellesmere Port. They were probably formed at the same time. They were predated by the Coal Measures boundary fault, which is closely associated with Armorican structures of similar trend west of the Dee.

5. Relation to Older Structures

The exact direction of structures beneath the thick Triassic cover of Wirral has not been definitely determined. Away to the north-east, however, the Coal Measures emerge in the Wigan and St. Helens areas. There, the fold axes and fault trends are north-east to south-west and north-west to south-east. The structures in the Wigan area described in the Geological Survey Memoir (1938), are shown to be relatively simple to the east of the Great Haigh fault. The dips in the Permian and Triassic strata are about half those in Carboniferous rocks, and the throw of the faults is also about half. The strike is nearly the same. To the west of the Great Haigh fault the dip and strike of the post-Carboniferous rocks begins to differ considerably from that of underlying deposits.

South-west of Wirral, on both sides of the Dee Estuary, structures in Carboniferous rocks are from north-west to south-east and the boundary fault at Neston follows this direction. It therefore seems likely that the intervening sub-Wirral area is floored with rocks of similar trend. Thus the structures of Triassic rocks are not directly connected with those of Armorican or pre-Permian date. This is seen in the Wigan area west of the Great Haigh fault and can be inferred from the swing of the axis of the Heswall syncline and Mid-Wirral faults as they near the boundary fault. The Wirral structures are therefore not simple movements along older lines but are largely independent of earlier folds.

6. The Age of the Structures.

Owing to the local incompleteness of the stratigraphical column, it is very difficult to assign a date to the folds and faults of Wirral. Primarily they are post-Triassic and pre-Boulder Clay. The limits can be narrowed rather more than this, however. In the Whitchurch-Wem region of Cheshire and Shropshire, Rhaetic and Lias deposits succeed the Keuper conformably. A similar sequence is seen near Carlisle in Cumberland. The structures are therefore undoubtedly post-Liassic. Platforms,

unwarped, have been observed by A. A. Miller within the Cheshire basin (1938), one at about 450 feet. From its height, this platform may be of late Pliocene age.

In the south of England Miocene folding occurs along north-to-south and east-to-west axes, the latter being much the most important. It seems probable that ripples running northwards from the southern centres of movement would be found in soft rocks of sufficient depth to take them. Thus the basin of Cheshire and South Lancashire, containing thousands of feet of Triassic strata and possibly as great a thickness of later deposits, was folded and faulted along Miocene lines. At Neston, where the more compacted Coal Measures occurred, the structures were forced against a solid block, and they changed their direction. East of the Great Haigh fault, where deposits were thinner, the structures followed older lines, the Armorican folds deepening and the Armorican faults extending their throw.

The thickness of the Bunter Sandstones in Wirral is about 2,800 feet. The Keuper Series is incomplete, but it reaches approximately 3,000 feet in Mid-Cheshire. With the exception of the Keuper Basement Beds, the strata are mostly of poor consistency throughout. In consequence they are susceptible to warping. Most of the faults are to be found in the Keuper Basement Beds, and this is in keeping with their greater rigidity. The cracking of the two highest anticlines may be due to the solidity of the Carboniferous floor which possibly would not fold with the softer Trias.

It is also noteworthy that the major east-to-west folds in the south of England are asymmetric, the Isle of Wight and Purbeck structures being monoclines. The larger folds of similar trend in Wirral are also monoclines.

7. Conclusions

Post-Triassic folding and faulting in the Wirral Peninsula appear to have their origin in the Miocene period. The general trends are north-to-south and east-to-west, except where they have been modified by proximity to the older rocks of the south-west. These folds are considered as ripples from the Miocene earth storm of Southern England, and are shown to be quite separate from older structures. Two cracked anticlines are described, which bring confirmatory evidence of the independence of post-Triassic and earlier folding.

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The Monio-Cambrian Interval

By Edward Greenly

NEARLY thirty-three years ago, in September, 1913, I searched the Harlech Grits for pebbles of the Mona Complex; and the search was a success: I obtained quite enough for a decisive demonstration. Still, their numbers were not great, and to obtain them had needed persistence; the search, indeed, occupied fully a fortnight. I sought a reason at the time in the horizons from which they came, for they were not from the Cambrian base. We shall presently discern a far more cogent reason: between the Cambrian and the Complex there is more than one formation. The surprise is not in their moderate numbers, but rather that there were any at all.

The Age of the Careg-onen Beds

In my later allusions to these beds I was inclined to regard them as Cambrian. Consider, however, the following points:

1. If the cleavage at Careg-onen beach were of Palaeozoic date, the local Ordovician shale would be very strongly cleaved, whereas it is hardly cleaved at all.

2. Though the Ogwen Cambrian is some 5,000 feet in thickness, it is much attenuated from the Cambrian of the Harlech axis. Ramsay attributed this to an Arenig overlap, but Nicholas was able to show that there is unconformity. Between Tregarth and the Strait the Ogwen Cambrian has been completely overstepped, for at Garth Ferry the base of the Extensus Zone rests directly upon the Complex. Thus there is overstep all the way from the Harlech axis. Should we then expect that four or five miles further on the Cambrian would reappear? Yet that is what has taken place if these beds be Cambrian.

3. At the base of the Cambrian where we finally see it, there are 300 or 400 feet of conglomerate; the basement grit at Careg-onen is about six inches thick.

4. In the Arvon Cambrian there is a very pale, sea-green slate which, though thinner than its neighbours, has been traced for a mile or more. It is not very low in the series, whereas that of Careg-onen is only six inches from the base. Immediately above this bed is a rather remarkable red slate, not less than 1,000 feet in thickness, perhaps the most important member of the Arvon Cambrian, which has no counterpart in the Careg-onen Beds.

5. At Careg-onen there is a thin ironstone. In the Arvon Cambrian, which has now been mapped on the 25-inch scale, no ironstone at all is known.

6. The Careg-onen Beds are peculiarly siliceous—very much more so than anything in the Penrhyn Slates.

7. In the Ogwen Cambrian, two horizons have yielded fossils; in the lower portion, the *Solenopleura* fauna, while one of their higher beds is positively crowded with *Lingulella davisii*. The formation we are considering, though searched for two full days by the able and eager Muir, did not yield a single fossil visible to the unaided eye. Not one distinctive Cambrian fossil has ever been found in Anglesey.

8. In our own Cambrian (Arvon, that is, and the margin of Snowdonia), so I am told by Dr. Stubblefield, who has recently made a study of the *Solenopleura* fauna, he has not met with a single spicule. In the Careg-onen Beds, we find them at once and in abundance; with, moreover, such persistence as to be "characteristic fossils". Similar spicules, it is true, are known in the Menevian Beds, but that is on the coast of Pembroke, fully 100 miles away.

Any of these considerations, taken by itself, would be enough to render doubtful an ascription of Cambrian age; when they are taken together, that becomes incredible.

Can they then be of Arvonian age? This, too, seems impossible. All the Arvonian is volcanic, so far as ascertained, and while eruptions were proceeding, there must have been great clouds of dust hanging in the air for miles. Much of this would fall into the sea, if the sea were near enough, and Coch-y-miéri is not very far away. Such a formation would be hemi-pyroclastic, whereas the Careg-onen Beds are not. Further, with heavy showers of dust rendering the water turbid, sponges would not flourish there.

The Mierean Formation

If neither Cambrian nor Arvonian, but a distinct formation, the Careg-onen Beds are of exceptional interest, and well deserve a name. We think at once of "Careg-onian", but the formation will have to be discussed in relation to Arvonian and in prose writing, rhyme is undesirable. I propose, therefore, that we name it Mierean, because at Coch-y-Miéri it is unusually rich in spicules. Above its basal grits, most of the Mierean is decidedly fine in texture.

The Trefdraeth Conglomerate.—In default of evidence to the contrary, this may very probably be regarded as Mierean. True, no spicules are on record, but in a coarse conglomerate they could hardly be expected. One character is significant; this conglomerate is extremely rich in debris of the Mona Complex, very much more so than either the Cambrian or the Arvonian. So, too, is the basement Mierean.

The chronological value of the Mierean.—The thickness of the Mierean is unknown, for its top is never seen; even at Careg-onen the higher beds are concealed by thrusting. There is, however, another criterion. We have had occasion to note its singular siliceousness, and this siliceous cement is exceedingly fine of texture, being apparently in the nature of chert. And chert is a slow-forming rock.

The Relative Ages of the Mierean and the Arvonian

Our impulse is to suggest that the Arvonian is the older of these two formations, because of its extent and thickness; but the following points should be considered:

1. No formation has ever been seen in the Arvonio-Cambrian interval,[1] yet were the Mierean the later that is just where it should be found.

[1] In the *Geological Magazine* for 1944, a suggestion was made that the grit of Moel-y-ci (which is certainly post-Arvonian) might belong to this interval. No Cambrian, however, adjoins it, so the suggestion remains conjectural. The grit has no resemblance to anything in the Mierean.

2. The evidence of the pebbles, though it is negative, is strong. More than one member of the Arvonian, in particular the granite, is a most kenspeckle [1] rock and in the Cambrian has been recognized as pebbles: never in the Mierean.

3. The Arvonian at Baron Hill is 1,000 feet thick, most of it a very fine dust-rock. This could not have thinned away between Beaumaris and Mynydd-Llwydiarth unless the winds were from the north; and such evidence as we have (the position, that is, of the coarse agglomerates, pointing to the principal centres of eruption) is suggestive of winds from the opposite quarter.

The Mierean, wherever we see it, rests direct upon the Complex. So, if unexpectedly, we infer that the Mierean is the older of the two.

The Bwlch-gwyn Rhyolite

This must once have been thick and extensive, a formation of importance; yet very little is left to-day. When treating of it in the Anglesey Memoir, I was inclined to correlate it with the fluidal rock of Cwm-y-glo, which it certainly resembles. This resemblance, however, is illusive. I had at that time made no study of the rhyolites of the Arvonian, and had not become aware of their strongly kalian composition. The Cwm-y-glo rhyolite has not been analysed, but orthoclase is its dominant felspar; whereas this Bwlch-gwyn rock is about as natrian as a rhyolite well can be. Besides its porphyritic albites a singular circumstance tells of the nature of its matrix. Certain of its curving bands which, in ordinary light, seem to be merely fluidal, are found when viewed between crossed nicols to have undergone a change into a sort of mosaic of albites. Returning to ordinary light, and bearing in mind which these bands are, a thin curving fluidal thread is found to run right through these albites just as though they were not there. The matrix, it is evident, has the composition of albite; at any rate very close to that. It cannot therefore be Arvonian, and we know that it is not Ordovician. In unequivocal Cambrian [2] no such rock has ever been found, at any rate in the British area. We have, however, convincing evidence that it is pre-Mierean. In the Plastirion outlier there is a thin conglomerate with pebbles up to an inch in length, of a quartz-rhyolite with very pronounced fluidal structure. The felspars have not been determined, but in this particular case that is hardly necessary, since for many miles around the only fluidal rock with porphyritic quartz is this Bwlch-gwyn rhyolite. From Plastirion to Bwlch-gwyn is rather more than four miles and a half, but the pebbles are smoothly rolled, and must have travelled for some distance. They may not, however, have come from Bwlch-gwyn itself, for in Mierean times the rhyolite must have been larger. That it was a lava there can be little doubt, for its fluidal structure is pronounced and thoroughly pervasive; there is confirmation of this in its excessive wastedness, for had it been a sill it would have been under strong protection. Again, it is long

[1] A very expressive Scottish word signifying something which we shall know when we see it again.

[2] In writing "unequivocal" I allude to the views of Geikie, who regarded Arvonian as Cambrian.

subsequent to the Complex, and thus not likely to be much pre-Mierean ; there would hardly have been time for such stripping of a sill as would permit the production of these pebbles.

FORMATIONS OF THE MONIO-CAMBRIAN INTERVAL

We have thus learned of the following series :

Cambrian
  Arvonian
  Mierean
  Sodic-rhyolite of Bwlch-gwyn
Mona Complex

and this may not be the whole succession, for with erosion so severe there may well have been formations that have vanished altogether.

The sodic-rhyolite rests upon mica-schist, a rock which cannot have been produced at or even near the surface, so that a higher tectonic horizon has been swept away completely. The rhyolite in its turn was reduced by pre-Mierean erosion, while the grits of the Mierean are crowded with fragments of the Complex.

There are no sediments in the Arvonian, so that the Mierean sea must have rolled away completely, and a very extensive region elevated into land. And in the Arvonio-Cambrian interval there was very deep erosion exposing even such a rock as the granite of the Twt.

Inserting these intervals, we have :

Cambrian
  Deep erosion
  Arvonian
  Elevation
  Mierean (marine)
  Erosion
  Sodic-rhyolite of Bwlch-gwyn
  Destruction of higher tectonic horizon
Mona Complex

We have now obtained some measure of the Monio-Cambrian Interval. Does it not recall to mind a very famous interval, the interval between the Lewisian and the Zone of Olenellus ?

Postscript.—It is not at all unlikely that, on Mynydd Llwydiarth or the Llanddona Highlands, there may be outliers of the Mierean which have not yet been detected. They would probably be very small, since an outlier twenty yards in diameter would hardly have escaped detection ; but they would reward a search, for the sake of their relationships to the Complex.

An Augitite from S. Vicente, Cape Verde Islands

By Gerald M. Part

TWO specimens of Augitite (Nos. 64613–4) in the British Museum (Natural History) were collected during the voyage of H.M.S. *Challenger* (1872–6) and acquired by the Museum in February, 1890, through the Director of the Challenger Office, Dr. (later Sir John) Murray. The rock was briefly described by Renard,[1] who noted the fibrous texture and unusual elongation of its pyroxene, as "related to the pyroxenites".

The specimens are labelled "dyke, Bird Island, near St. Vincent, Cape Verde Islands", a locality which may possibly be Ilheu dos Passaros, off the N.E. horn of Porto Grande, Mindello. The main portion [64614] about $2\frac{1}{2} \times 1\frac{1}{2} \times 1$ in. in size is dark grey in colour and "woody" in appearance due to the number of narrow, elongated, and parallel vesicles. It also shows numerous thin, elongated phenocrysts of black augite up to 5 mm. or more in length with the same elongation and parallelism as the vesicles except at one end of the specimen where both vesicles and phenocrysts die out and the rock assumes a finer and more massive character. This presumably represents the margin or near-margin of the mass. [64613] is similar in character to the other specimen.

Mineralogically the composition is simple—phenocrysts of clove-brown titan-augite set in a ground-mass of pale-brown to colourless glass densely charged with cubes of magnetite and microlites of similar titan-augite (up to 0·02 mm.). The phenocrysts are very elongated (up to 5 mm., with a length-breadth ratio of at least 12), in the c-direction and also flattened parallel to (100). Most of the vesicles have a lining of pale glass, but some also contain a late filling of felspar, either oligoclase Ab_{76} or more rarely a soda-orthoclase. Other patches, probably originally vesicles, are filled with glass containing titan-augite apatite and occasional elongated flakes of biotite, but coarser in texture than the general ground-mass of the rock. Many of the little pyroxenes show hour-glass structure, some are twinned parallel to (100).

The R.I. of the pyroxene is decidedly high, even by Cape Verde Island standards, α 1·720 γ 1·742 ($\pm$ ·002), as also are the extinction angles, there being a progressive change in the value of these, as shown below.

Z/c	microlites of marginal ground-mass .	54–56°
	phenocrysts (interior zones) . . .	56–59°
	,, (outer skin)	up to 63°
	microlites of vesicular ground-mass .	up to 63°
	Pyroxene of late infilling . . .	65°

The main interest of the rock lies in the texture, with its remarkable parallelism in the pyroxenes elongated normal to the apparent cooling surface (Text-fig. A). Over limited areas these behave optically as a unit, but sectioning has failed to reveal any material connection between the individuals making up any particular group. Towards the denser, outer, portion the pyroxenes become plumose in character and more and more ragged with magnetite entangled in the margins, but growth seems to

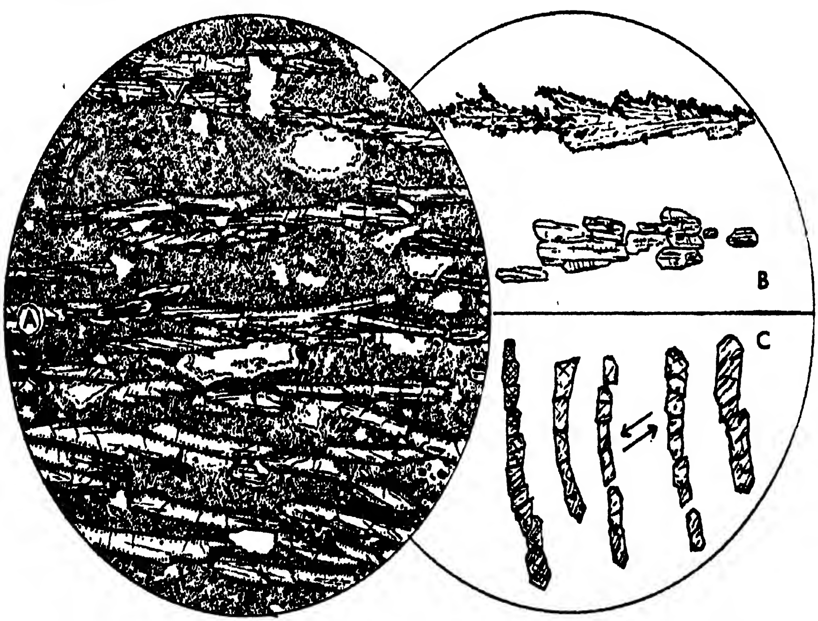
[1] Renard A. *Challenger Report*: Physics and Chemistry, II, pt. viii, 1889, 17.

have started from some point in the interior and proceeded towards the margin of the rock as indicated by the plumose terminations of the crystals in this direction (Text-fig. B).

The microlites of the ground-mass have a different orientation parallel to the cooling-surface and therefore across the line of elongation of the phenocrysts. A section cut in this direction shows also that flow, continued during consolidation of the ground-mass, has imposed shearing stress on the large pyroxenes which have bent and repeatedly broken along one prismatic cleavage (Text-fig. C).

It seems desirable to put this interesting and rather unusual example of micro-texture on record and to hope that some future collector will bring more of the rock home so that we may trace the changes across the whole width of the mass. The evidence is not conclusive, but the vesicular character of much of the specimen suggests that the original collector may have been in error in attributing it to a dyke.

I take this opportunity to express my thanks to the Trustees of the British Museum for their courtesy in placing this material (amongst much other from the Cape Verde Islands) at my disposal for examination and description.



TEXT-FIG. 1.—Augitite, Bird Island. S. Vicente, Cape Verde Is. [BM. 64614.]
A × 18. Section parallel to elongation of vesicles and phenocrysts.
B × 10. Plumose phenocrysts towards marginal part of specimen.
C × 10. Phenocrysts bent and broken under shear.

REVIEWS

ELEMENTS OF GEOLOGY, FOR WESTERN AUSTRALIAN STUDENTS. By E. DE C. CLARKE, R. T. PRIDER, and C. TEICHERT (of the Department of Geology, University of Western Australia). 1944. pp. 301, figs. 117.

ELEMENTARY PRACTICAL GEOLOGY, FOR WESTERN AUSTRALIAN STUDENTS. By the same authors. 1946. pp. 170, figs. 32.

Both published by the University Text-Books Board, at the University of Western Australia, Nedlands, Western Australia, and obtainable for 21*s*. and 15*s*. (Australian), respectively (sterling prices 25 per cent less).

These two works are comprehensive first-year university text-books. They have been produced in war time under considerable difficulties, but are printed on good paper and are adequately bound, and come at just the right time when the University of Western Australia, like other universities all over the world, is being swamped by the rush of post-war students.

The first volume is of considerably more than local interest, however, and overseas readers may be glad to know something of it. In particular, it may serve as an introduction to the geology of Western Australia, and in that connection contains many new unpublished data, as well as marshalling the existing information, at present scattered through the pages of the Geological Survey bulletins, the local Royal Society proceedings, and many other journals.

The general plan of the work is orthodox, 180 pages going to Physical Geology, and 90 pages to Historical Geology. As might be expected, however, special attention is given to the arid cycle of erosion, although glaciation is not neglected, since this is of great importance here during the Permian. Again, as is only right in such a region, the pre-Cambrian gets fairly thorough treatment. The subsequent systems are illustrated by a series of Australia-wide palaeogeographic maps, which should be of considerable interest to readers abroad and it may be a matter of some interest to geologists trained on the classical areas of Scotland, Wales and the Appalachians, to see how the same principles may be taught in an entirely remote setting.

Professor Clarke's character is one of cautious liberalism; this admirable balance is to be seen and felt throughout the pages of this work. The contentious subjects of continental drift, geotectonics, and eustatism have been carefully screened from the ears and eyes of the first year student, whose activities have been directed, by means of numerous sketch-maps and diagrams, to the practical side. The more advanced man can then choose for himself when he comes to the grander concepts of geological theory.

The second volume is essentially a laboratory and field companion to the first. It is of little interest to geologists not actually concerned with teaching. It may be noted, however, that here, in one volume, the beginner may find an adequate practical treatment of mineralogy, palaeontology, field work, and indoor mapping, for which normally he is expected to purchase three or four volumes, each of which contains a good deal that is above his head, and therefore, perhaps confusing to the first year man, as well as involving him in unnecessary expense.

R. W. F.

DATING THE PAST. An Introduction to Geochronology. By F. E. ZEUNER. pp. xviii + 444, with 24 plates and 103 text-figures. London: Methuen, 1946. Price 30*s*.

The main object of this book is the discussion of the possibility of finding an absolute date in years for prehistoric events. By much the greater part of it is devoted to Prehistoric Archaeology, less than a quarter of the book dealing with anything older than the Pleistocene. The use of this last word gives an opportunity for a protest against the employment by geological writers in general of the terms Holocene or Recent and Post-glacial as indicating definite epochs of time. The first is meaningless as usually defined, since species are becoming extinct all the time. One possible definition, for example, would be the time that has elapsed, just 100 years, since the last Great Auk died. Post-glacial is just as bad: nothing could be much more glacial than the present condition of Greenland and Antarctica, and glaciers come down to tide-water in other lands as well.

The dating methods here employed may be classed under two groups: direct methods such as radioactivity, rate of sedimentation, salt content of the sea and so on, and, used much more extensively, a combination of astronomical theory, with special stress on the work of Milankovitch on solar radiation, and climatic fluctuations, stratigraphy, and archaeological investigations.

The first chapter contains an account of tree-ring counting, while the second and third deal with pollen analysis and varve-counting. Here and there is to be discerned a note of healthy scepticism, as if the author was just a little doubtful as to whether some of the foundations are quite strong enough to bear the superstructures that have been piled on them, while throughout there is little tendency to push an argument for more than it is worth.

Then follow six chapters on Prehistoric Archaeology, or rather, it would be fairer to say, on those parts of that immense subject where the author thinks definite dates in years can be assigned. It must be admitted that some parts make rather tough reading, for a variety of reasons, one of which raises another question of a general nature: that is the problem of numbering successive deposits or events. Most authors, happily, number upwards, that is, beginning with the earliest, but a good many, unfortunately, number downwards. There is here the added difficulty in the printing of tables. Several times in this book tables are printed with the newest at the bottom, which is confusing. Some general agreement among geologists on this matter is highly desirable. There are, of course, complications, e.g. when dealing with river terraces, on which so much is now being written, where the highest *is* the oldest. Another instance is the discovery of episodes preceding those already known. For example, there is now some evidence of glaciations in the Alps older than the Günz. Dr. Zeuner adopts a plan which avoids this difficulty for the four great glaciations of Europe, which he calls Early, Antepenultimate, Penultimate, and Last, and on this he founds a kind of symbolic notation: as for example, ApIgl is to be read as "Antepenultimate Interglacial". This at any rate saves a lot of type throughout the book. Another hindrance to easy reading is that every page or two some new

and uncouth name, usually of a cultural phase, is shot at the reader without any explanation of what it means.

Chapters x and xi, together about 45 pages, deal with geological events before the Pleistocene and with the Age of the Earth. A good many pages are taken up, rather unnecessarily, with a long and detailed account of the theory of radioactivity, with all its complications, from uranium and thorium to lead and helium. Most people have heard quite enough about uranium lately. The older methods of age determination are dismissed generally and justifiably as quite unreliable.

The last chapter deals with biological evolution, so far as it can be dated by any method. The general conclusion seems to be that it takes half a million years to establish a new species. As bearing on this subject, it may be noted that what specially strikes one on reading this book is the extraordinary slowness of human development in at least 95 per cent of the time man is now supposed to have existed as compared with the much too rapid progress of the present.

There is an enormous bibliography, 33 pages, and a very complete index.

R. H. R.

THE GEOLOGICAL HISTORY OF QUEENSLAND. A Stratigraphical Outline, by W. H. BRYAN and O. A. JONES. University of Queensland Papers. Vol. II, No. 12, pp. 103, with 13 maps. 1946. Price 7*s*. 6*d*.

As the State of Queensland is about eleven times as large as England and Wales, it affords room for a good deal of geological variety. Consequently, as the authors themselves say, it is difficult to write a short and concise book on the subject, without over-simplification. However, so far as can be judged without local knowledge, they have been successful in their task. At any rate they have produced a definitely readable story which includes many points of more than local interest. Some few of these may be briefly referred to here.

Perhaps the most notable feature of the geology of Queensland is the sharp contrast between the east and west of the State. In the west the story begins with a geosyncline, which soon converted itself into a permanent stable area, while in the east the great Tasman geosyncline persisted from the earliest times to the end of the Carboniferous. After this there was no more marine deposition, except for a short time in the Cretaceous, anywhere in the State. All the rest is of freshwater origin, and the Gondwana facies is prominent.

Not much is known about the Precambrian, but three revolutions have been established, leading to a four-fold division, with gneisses and schists in the two earlier ones, while in the third comes the Mount Isa Series with its rich mineralization (Ag, Pb, Zn, Cu) in the far west. In this same area some 60,000 square miles of Cambrian, with quantities of trilobites, would seem to afford a paradise for specialists. The fauna, which begins with a *Redlichia* zone, seems to have Chinese affinities. It is sad to find, however, that the Cambrian of the much more accessible eastern region is geosynclinal and unfossiliferous. In this same region a succession 18,000 feet thick attributed to the Ordovician has so far yielded one single, miserable specimen of a Diplograptid. The Silurian and Devonian,

confined to the eastern geosyncline, are rich in corals, and the Carboniferous contains no coal. This ends the geosynclinal facies.

Then comes orthodox Gondwanaland, with the *Glossopteris* flora, tillites, and a great development of excellent coal, including what is believed to be the thickest seam in the world (up to 93 feet, averaging 75) of clean hard black coal. The authors do not use the term Permo-Carboniferous, as in their opinion most if not all of these strata will eventually be found to be Permian. This view seems to be open to criticism, as the recent trend seems to be to depress the lower Gondwana beds in most countries into the Carboniferous, and the Permian System as a whole is rather under a cloud at present.

Henceforward, with the small exception before noted, all is fresh-water deposit, with much good coal. The *Glossopteris* flora is followed by *Thinnfeldia*. In the Tertiary and Pleistocene comes a marvellous collection of Marsupials, including *Diprotodon*, bigger than a rhinoceros, and giant birds.

Volcanic episodes are numerous and specially notable in the late Precambrian and Lower Cambrian and in the Pliocene. Tectonic episodes with granites happened in the Precambrian, late Devonian, Permian, and Upper Cretaceous. Space will not allow of any discussion of the important ore-deposits, which include such famous names as Mount Isa, Mount Morgan, and Charters Towers. The tin and wolfram ores of the far north are of Permian age.

All this indicates a sufficiently variegated history, and as the authors fully admit, there are many controversial matters, but the main point is the strong contrast between geosynclinal sedimentation on the one hand, and transgressive marine and lacustrine deposits on the other.

R. H. R.

BARIUM MINERALS IN ENGLAND AND WALES. By K. C. DUNHAM and H. G. DINES. *War-time Pamphlet* 46, *Geological Survey*. pp. v + 149, with 17 figures. 1945. Price 6*s*. 9*d*.

In his preface the Director points out that this publication is in reality a new and revised edition of volume ii of that valuable series of *Special Reports on Mineral Resources*, issued by the Geological Survey from 1915 onwards, and now produced in its present form to supply much sought-after information as quickly as possible.

The uses of barium minerals, barytes, and witherite are surprisingly numerous and often unexpected: most people know barytes vaguely as the foundation of white paint with the advantage of not being blackened by sulphur fumes, like white lead. Witherite is often regarded by academic mineralogists as a somewhat rare mineral, so that it is of interest to find that the total production of the Settlingstones mine, a few miles from Hexham in Northumberland, has been about 383,000 tons, and the Fallowfield mine, also near Hexham, has produced about 100,000 tons. But there are few other important deposits.

Barytes, on the other hand, is one of the commonest non-metalliferous minerals in lead-zinc deposits, usually occurring in the upper levels or outer fringes of mineralized areas. In the Pennines it often surrounds vein-complexes characterized by fluorspar. In this memoir nine chief

areas are recognized, but those south of Shropshire do not count for much. Broadly speaking, the workable deposits are concentrated in the Shelve district of Salop, Derbyshire, Yorkshire, Cumberland, Durham, and Northumberland. Nearly all the northern ones are in Carboniferous rocks, even a few in the Coal Measures, but in Shropshire in the Ordovician, with some in the Western Longmyndian.

CORRESPONDENCE

THE OCCURRENCE OF MOINE SCHISTS IN IRELAND

SIR,—In Counties Donegal (Eire) and Fermanagh (Northern Ireland), near Ballyshannon, Belleek, and Pettigo, there is an extensive tract of hill and moorland country, north of the River Erne and Lough Erne, occupied by metamorphic rocks. On Sheets 24, 31, and 32 of the one inch to the mile Geological Map of Ireland, these metamorphic rocks are depicted in a different colour from metamorphic rocks further north forming the greater part of County Donegal. In the Explanatory Memoir on Sheets 31 and 32 (1891), it is suggested that while these more northerly metamorphic rocks can be correlated with the Dalradian Schists of Scotland (a view now generally accepted), the metamorphic rocks near Lough Erne belong to an older formation of Lewisian (Archean) age. A description of the schists near Pettigo was later given by Cole (1900),[1] who also believed them to be of Archean age.

Recently the writer had the opportunity of examining the metamorphic rocks near Ballyshannon and Lough Erne. In his opinion there is no resemblance between these rocks and the Lewisian Gneisses of Scotland. On the other hand, the appearance in the field and the lithology of these rocks are such that the writer has no hesitation in correlating them with the Moine Schists of Scotland, a view which is supported by comparison of hand specimens and thin sections with those of Moine Schists from various parts of the Scottish Highlands.

The commonest rocks are well bedded quartz-mica-granulites or psammitic schists varying from white, highly quartzose types to darker, grey, biotite-rich types. Thin, muscovite-rich laminae are usually present; minor bedding planes are marked by thin colour layers, due to the concentration of dark minerals. Current-bedding was noted at several localities. Thoroughly pelitic rocks (muscovite-biotite-schists) are also present. Small intrusions of epidiorite (hornblende-schist) are common. In the western part of the area, near Ballyshannon, the rocks are of fairly low metamorphic grade and are strikingly straight-bedded and flaggy in appearance. Further east they become more coarsely crystalline, are often massive, and the bedding is locally strongly contorted. In this area of higher metamorphism pegmatite veins are abundant, while the pelitic schists are intimately injected with pegmatitic material along the foliation planes.

North of Lough Derg the metamorphic rocks for which a Moine age is here postulated pass under the Dalradian rocks (quartzites, mica-schists, and limestones). On their west and south-west sides they are unconformably overlain by Carboniferous strata, and to the east

[1] On Metamorphic Rocks in Eastern Tyrone and Southern Donegal. *Trans. Roy. Irish Acad.*, vol. xxxi, pp. 431–471.

and south-east they are brought against similar strata by a powerful north-easterly fault.

In Scotland the Moine Schists have long been known to occupy vast areas, both in the Northern Highlands, and in the Central Highlands where they pass southwards under the Dalradian. Their reappearance on the south-west side of the latter in Ireland not only greatly extends the known range of the Moine Schists, but also suggests that they form a basement for much, if not all, of the younger Dalradian formation.

On completion of further field and petrographic work it is hoped to publish a more detailed account.

19 Grange Terrace,
Edinburgh.
J. G. C. ANDERSON.

17th July, 1946.

CAEN UNIVERSITY GEOLOGY DEPARTMENT

SIR,—In Volume 81, No. 5 (Sept.-Oct., 1944) you were good enough to publish our appeal on behalf of the Geology Department of Caen University. We would like to thank the numerous donors who responded beyond our hopes, and we think it would interest them individually to know what they have collectively enabled us to do to help Caen in its plight.

Donations amounted to £146 7*s*., of which we have spent £64 5*s*. 6*d*. on British geological books and maps, and some £20 on a prism binocular, pocket lenses, and Canada balsam, all asked for by Professor Dangeard. The most valuable single donation in kind was a set of the *Quarterly Journal* from vol. 23 (1867) to the present day, presented by Mr. A. G. Stenhouse, together with numerous Survey memoirs and Summaries of Progress, and a dozen standard geological books now for the most part unobtainable. Bristol University are sending independently 13 more volumes of the *Quarterly Journal*, taking the set back to volume 10 (1854), a nearly complete set of the Palaeontographical Society's monographs and a nearly complete run of the *Geological Magazine* from Vol. 1 to, Vol. 67 (1930). We have completed the *Geological Magazine* as far as it is in print, at a cost of £23 18*s*. 6*d*., and the Council of the Palaeontographical Society has presented the parts needed to complete the set of their monographs. We have also been promised a run of the *Proceedings of the Geologists' Association* from 1920 to 1944. In addition, we have received and forwarded about 40 lb. of reprints and, through the War Office, a set of 85 maps of France on the 1/80,000 scale ; and other donors have sent representative collections of labelled British Cretaceous and Tertiary fossils. It is proposed to hold the remainder of our funds in reserve for the purchase of other books asked for by Professor Dangeard, but not at present obtainable, and important Geological Survey publications as they become available.

We are indebted to the British Council for forwarding the books and collections piecemeal. Everything sent has been reported by Professor Dangeard as arrived in good condition.

J. A. DOUGLAS,
W. B. R. KING,
C. J. STUBBLEFIELD,
C. W. WRIGHT,
W. J. ARKELL.

10th May, 1946.

FIG. 1.— Basic dioritic xenoliths enclosed in the tonalite of the Foyers "Granite" complex. Shore of Loch Farraline at Errogie.

FIG. 2.—"Intrusion breccia" of schist fragments on the margin of the Foyers "Granite" complex. Summit of Carn Gairbhthinn.

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The Geology of the Foyers "Granite" and the Surrounding Country

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(PLATE XV)

I. Introduction

THE district of Strath Errick and Foyers, with which the investigation recorded here is concerned, occupies about 70 square miles south-east of Loch Ness, in Inverness-shire. The ground rises steeply from the loch to form a bordering ridge, beyond which it slopes more gently to Strath Errick. Further to the south-east, the hills rise to a height of 2,560 ft. in Beinn Bhuraich. The country is chiefly moor and hill grassland, with numerous exposures of rock; fairly extensive areas are under arable cultivation in Strath Errick. The district is drained by the Rivers Fechlin and Farigaig, both of which enter Loch Ness through deep gorges (Text-fig. 3).

The geological rock-groups present are:—

Pleistocene and Recent	Peat. Freshwater alluvium. Fluvio-glacial sand and gravel. Boulder clay.
Middle Old Red Sandstone	Conglomerates with thin sandstone bands. Basal breccia. Rests with strong unconformity on the schists and Foyers "Granite".
Foyers "Granite"	Plutonic complex of Caledonian age, consisting of (apart from a little early appinite) tonalite, granodiorite, and granite. Intruded into Moine schists.
Moine Schists	"Injection" (permeation) gneisses. Semi-pelitic and siliceous schists.
? Lewisian	Gleann Liath series, including the Foyers limestone.

Prior to the present investigation, very little geological research had been done in this district, although the presence of a large granitic mass had been known for some time. A. Boué (1820, p. 20, 102) described the outcrops of "granite" near the Falls of Foyers, and the neighbouring Middle Old Red Sandstone. The boundary of the Middle Old Red Sandstone and its unconformable junction with the Moine schists at Creag

nan Clag were described by Wallace in 1879 (p. 204). The Foyers limestone has been recently described in one of the Geological Survey's war-time pamphlets on Scottish limestones (Robertson and Knox, 1942, p. 11). The outline of the Foyers " Granite " is shown with approximate accuracy on the 10 miles : 1 inch geological map of Scotland (published under the direction of Sir Archibald Geikie, 1910) : the district has not yet been systematically surveyed by the Geological Survey.

During the research (1944–6) described in this paper, some 70 square miles of country have been geologically mapped on the 6 in. scale : the Old Red Sandstone boundary has been traced from Loch Dun Seilcheig to Carn Dearg ; the Foyers " Granite " has been mapped and its rock types differentiated, and a study made of the series in which the Foyers limestone occurs.

II. The Gleann Liath Series (? Lewisian)

(*a*) *Field Occurrence*

The Gleann Liath Series (Text-fig. 1) outcrops along a narrow belt in Gleann Liath, bounded to the south-east by the Gleann Liath fault, and overlain unconformably by the Middle Old Red Sandstone to the north-west. Its relations to the Moine schists and the Foyers " Granite " are nowhere exposed. The series consists of coarse gneisses with associated limestones, intruded by basic hornblende-diorite and veins of pegmatite and granite. It is of markedly different facies from the neighbouring Moine schists. All the rocks are much affected by crushing and shearing due to the neighbouring Great Glen Fault and the Gleann Liath Fault.

The limestones and gneisses are highly folded, with a general N.E.–S.W. strike, from which there are, however, many minor deviations. Typically, the gneiss is a coarse muscovite-biotite-gneiss with knots and lenticles of pegmatite, but it passes locally into more siliceous and more pelitic varieties. Its outcrop extends along the flank of Gleann Liath from the Upper Falls of Foyers to Creag an Fhithich. The limestone, which is a highly crystalline marble, is found in two lenticular outcrops, the larger at the Foyers limestone quarry, the smaller at the Boleskine quarry. A highly sheared mass of basic hornblende-diorite forms the crags of Creag Nighean Iain Duinn ; the crushing to which it has been subjected has obliterated both the structure of the intrusion itself and its relations to the surrounding gneiss. The Gleann Liath rocks are much veined with pegmatite, in marked contrast to the neighbouring Moine schist country, where such veins are rare.

(*b*) *Petrography of the Gleann Liath Series*

(i) *Limestones.*—The limestone exposed in the Boleskine and the central part of the Foyers quarries, is a coarsely crystalline white marble, composed of interlocking plates of calcite. The bulk of the limestone at the Foyers quarry, however, is a hard blue marble rich in tremolite, diopside, phlogopite, zoisite, sphene, and epidote, with subsidiary quartz, plagioclase, zircon, apatite, and iron ore. The diopside is found both in

large, poikiloblastic crystals and in aggregates of small, compact individuals. In the more impure layers, where the limestone passes down into the gneiss, the tremolite blades reach a length of ½ in. The tremolite encloses minute zircons surrounded by pleochroic halos. The abundant epidote is often associated with the numerous small crush zones which traverse the limestone.

To the south-west of the Foyers limestone quarry, there is a small outcrop of a silvery tremolite-schist.

(ii) *Schists and Gneisses.*—The Gleann Liath muscovite-biotite-gneiss consists of laminae of partly chloritized brown biotite with subsidiary muscovite and accessory garnet, apatite, zircon, and black iron ore, alternating with broader lenticles rich in quartz associated with subhedral orthoclase and much sericitized sodic plagioclase. The larger plagioclase crystals frequently enclose blebs of quartz.

At Glenlia and above the Upper Falls of the Fechlin, the gneiss passes into a siliceous granulite, containing microcline ; some of the quartz grains show a peculiar watered striping. Elsewhere the gneiss grades into a soft, garnetiferous muscovite-biotite-schist, practically free from quartz and feldspar.

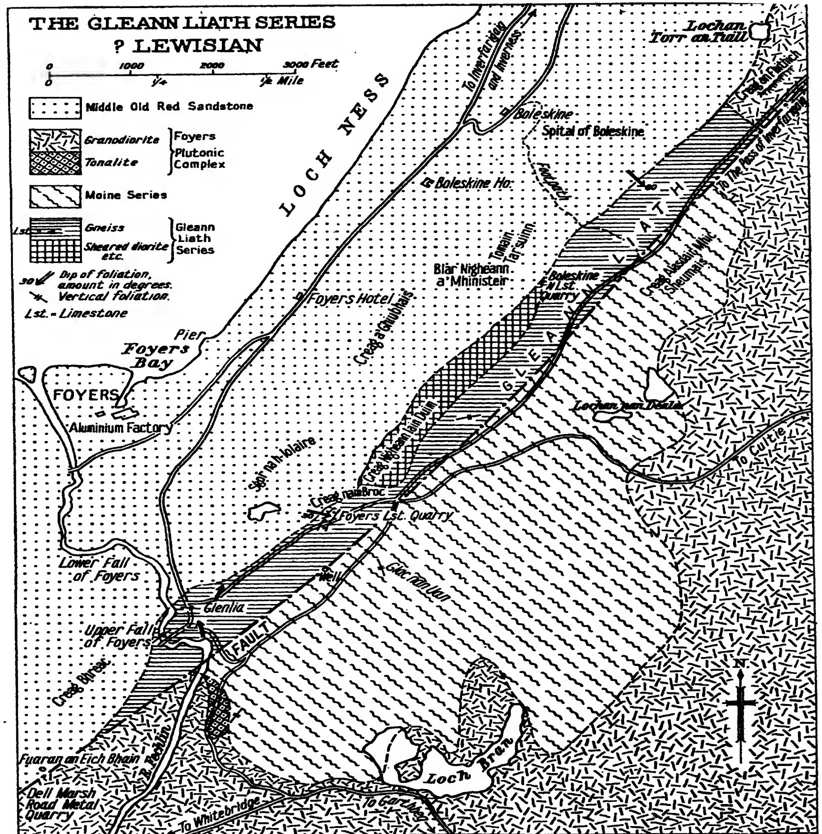
A hornblende-bearing granulite, exposed in an isolated outcrop, a third of the way along Gleann Liath from the Upper Falls, probably also belongs to the Gleann Liath series.

(iii) *Sheared Plutonic Rocks.*—The crags of Creag Nighean Iain Duinn consist of green crush-rock, exhibiting beautiful mortar structure in thin section, in which lie lenticular patches of less crushed material. For the most part, the latter consists of coarse black and red hornblende-diorite, composed of sodic oligoclase (An_{10-20}), green hornblende, and chloritized biotite with subsidiary perthitic orthoclase, quartz, and myrmekite, and accessory sphene, black iron ore, brown orthite, and colourless apatite. The shearing which the rock has undergone has bent and broken the plagioclase crystals, the bright red colour of which in hand specimen is seen in thin section to be due to numerous specks of brown alteration products. The biotite flakes are crumpled and the quartz grains have sutured edges and shadowy extinction. Epidote has been introduced abundantly.

There is some variation in the coarseness of the Creag Nighean rocks and some finer-grained varieties are present. At the top of the crag, there is a small outcrop of a much more hornblendic variety, in which the plagioclase has been albitized. All the rocks are rich in colourless accessory apatite in large, poorly-shaped crystals.

Near Glenlia there are small intrusive masses of biotite-granite (probably to be correlated with the Foyers plutonic complex), and of foliated, pale pink, muscovite-biotite-granite which is probably older. They have also been much sheared.

(iv) *Pegmatites and Aplites.*—Veins of pegmatite and aplite several feet in thickness and usually sheared are common. The pegmatites are composed of quartz and feldspar with either biotite or muscovite ; in the Foyers limestone quarry there is a pink graphic granite, cutting the limestone. Veinlets of lit-par-lit habit can be traced into the gneiss from some of the pegmatites.



TEXT-FIG. 1.—Map of the Gleann Liath Series.

III. The Moine Schists (Central Highland Granulites)

The Moine schists of Strath Errick have been involved in an extensive regional permeation or injection complex, the limits of which extend south-eastward beyond the boundaries of the district at present under discussion. The injection (migmatitization) of the schists is earlier than the intrusion of the Foyers " Granite ", since the latter both cuts and contact-alters the injection gneisses. However, not all the Moine schists have been affected by the permeation processes, and " normal " schist types bulk large in the hills round the plutonic complex.

The schists are highly folded isoclinally, often with vertical dips; the regional strike is north-easterly, but in the neighbourhood of the Foyers " Granite " it has been deflected to conform to the margins of the intrusive complex.

The Strath Errick schists are predominantly siliceous in character. They range from siliceous granulites, with some subsidiary quartzites, to semi-pelitic schists. There are a few thin bands of hornblende-schist. On Carn na Saobhaidhe, the siliceous granulites exhibit what appears to be current-bedding. Typical pelitic Moine schists are found further to the south, around Loch Killin, where they are associated with numerous thin bands of calc-silicate rock—garnetiferous hornblende-zoisite-granulites.

On Glen Doe, above Fort Augustus, and at Loch Tarff, silvery garnetiferous mica-schists with graphite and accessory tourmaline are developed. The garnets contain spirally arranged inclusions of graphite, and the schist is of Dalradian rather than Moine type. It is associated with garnetiferous granulites carrying free calcite. The mountain of Beinn a' Bhacaidh is carved in green schistose grits, very rich in epidote. Some of the epidote crystals have cores of orthite. Schistose grits without epidote are interbedded with the mica-schists on Borlum Hill above Fort Augustus. The relationships of these grits and mica-schists to the Moine series proper have not yet been investigated.

The commonest type of migmatite is a siliceous granulite with augen of quartz, orthoclase, and oligoclase. The feldspar augen enclose parts of the finer-grained matrix, and may be elongated athwart the schistosity indicating growth after the main movements had ceased. Every gradation can be traced from rocks containing few augen to rocks in which they are very abundant.

At Loch Conagleann, Loch Ruthven, and Brin, a coarse injection gneiss with a pelitic basis is developed. It is a garnetiferous muscovite-biotite-gneiss in which wavy black mica-rich layers alternate with broader, white quartzo-feldspathic lenticles. On the Brin Crag and Cas Garbh, the gneiss encloses basic lenticles carrying green hornblende as well as biotite, accessory sphene, and numerous pink, poikiloblastic garnets—up to an inch in diameter. The gneiss gives rise to characteristically rugged crags, below which lie extensive screes of fallen blocks.

IV. The Stratigraphical Position of the Gleann Liath Series

The Gleann Liath Series is of markedly different facies from the neighbouring siliceous Moine schists, nor does the Gleann Liath gneiss resemble

the injection gneiss of Conagleann and Brin. Limestones are not known to occur anywhere else in Strath Errick. Paucity of limestones is one of the characteristic features of the Moine series (Flett, 1923, p. 56); they occur in a few localities, e.g. Shinness in Sutherland (Read, 1926, pp. 126–7, 138–141), Rebeg, near Beauly (Horne, 1914, pp. 37–8, 101), and Kyllachy in the Findhorn valley (Horne, 1915, p. 26; Flett, 1915, p. 53). The Moine limestones are invariably associated with horneblende-schist, most of which is probably of sedimentary derivation. At Kyllachy, a pale green calc-silicate-hornfels with scapolite is associated with the coarsely crystalline white marble. The schists associated with these Moine limestones are all of Moine type and gneisses are absent; neither limestones nor schists show the complicated minor folding characteristic of the Gleann Liath rocks. On lithological grounds there appears to be no basis for a correlation of the Glean Liath rocks with the Moine Series.

Should the Gleann Liath Series then be grouped with the Dalradian? Dalradian rocks have not been recorded so far in this part of the Highlands, though it must be remembered that it has not yet been surveyed in detail. The garnetiferous mica-schists of Glen Doe (p. 252) very probably belong to the Dalradian Series, but they do not show any resemblance to the Gleann Liath gneiss nor is limestone known to be associated with them. Moreover, the Foyers limestone itself bears no resemblance to the nearest known outcrop of Dalradian limestone (Ballachulish limestone), at Kinloch Laggan (Anderson, 1944, p. 12), or to those further south, such as the Blair Atholl and Loch Tay.

A third possibility is that the Gleann Liath Series represents a small inlier of Lewisian age. It must be admitted that no Lewisian rocks have hitherto been recorded south of the Great Glen; the nearest inlier to the north of the Great Glen is that in Glen Urquhart (Cunningham Craig, 1914, p. 20–3, 101). The Glen Urquhart inlier provides excellent material for comparison with the Foyers rocks since it includes a good development of limestone. It consists of a series of paragneisses and limestone, in an anticlinal fold, whose axes trend north-west, and into which is intruded a mass of serpentine of uncertain age. The limestone occupies the core of the anticline and is succeeded by rusty micaceous gneiss with kyanite and feldspathic banded gneisses with basic patches and lenticles. The whole series closely resembles the much larger Lewisian inlier at Glenelg.

The Urquhart limestone is a white marble with bands rich in calc-silicate minerals. The pure while marble cannot be distinguished from the pure white variety of the Gleann Liath limestone. The calc-silicates include large green tremolite crystals, wollastonite, phlogopite, and diopside. Spinel and forsterite, characteristic of the Glenelg limestones have not been recorded at Glen Urquhart. The Urquhart limestone is cut by veins of coarse pegmatite; the whole development of limestone is on a much larger scale than in Gleann Liath, but with the exception of the presence of wollastonite, the two outcrops are of very similar type. The rusty-weathering, micaceous gneisses which succeed the limestone in Glen Urquhart, are rich in blades of blue kyanite. No kyanite has been observed in Gleann Liath; but in other respects the Glen Urquhart gneisses are of similar type to those developed in Gleann Liath.

Though no detailed correlation of the two inliers is possible, their general resemblance supports the theory that the Gleann Liath Series may be of Lewisian age.

V. The Foyers " Granite " Complex

(*a*) *Field Description*

The principal outcrop of the Foyers " Granite " complex is in Strath Errick, but a series of satellite intrusions extend south-west into Knockie Forest. The complex consists of three principal rock-types, together with a little early appinite, intruded successively :—

1. Tonalite
2. Granodiorite
3. Granite

The appinites, hornblende-rich diorites, were the earliest members of the complex and are now found only as sparse xenoliths in Strath Errick and as small satellite intrusions between Lochs Knockie and Kemp, and in the Moine schists around Loch Bran.

The tonalite, a coarse-grained, grey, hornblende-biotite-quartz-diorite with abundant accessory sphene, outcrops on the margins of the main complex. Its relations to the appinites are not exposed. The granodiorite differs from the tonalite in carrying numerous pink phenocrysts of perthitic orthoclase, having an average length of ½ in. Both tonalite and granodiorite show a marked lineation of their components, which conforms to the strike of the surrounding schists (Text-fig. 3, inset map).

Several modifications of the granodiorite are found in the satellite intrusions of Knockie Forest, where it is found intruding and veining siliceous schists. The Meall nan Aidhean type is finer in grain than the type rock ; the Cnoc Carrach type is more quartzose and contains much larger phenocrysts of orthlocase and also phenocrysts of plagioclase. Near Loch Kemp there are dyke-like masses of granodiorite-porphyry, a finer-grained, more quartzose granodioritic rock, with large phenocrysts of orthoclase.

The granodiorite is rarely seen to send veins into the tonalite ; the contact between the two is usually sharp, though in some places, the granodiorite becomes progressively poorer in orthoclase and grades into the tonalite.

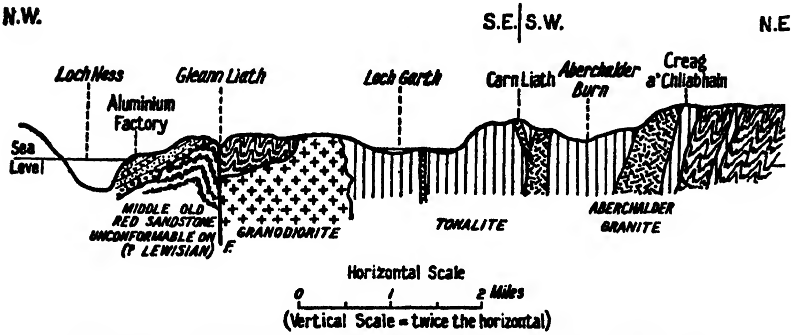
The final major rock-type is a pink, highly quartzose biotite-granite, poor in sphene and of finer grain than the preceding types. Its contacts with the earlier members are always sharp and usually near the vertical. Normally, it has a marked flaggy jointing. Much of its principal outcrop near Aberchalder is concealed under peat, but it appears to have the form of a complicated series of sheets and dykes cutting both granodiorite and tonalite.

Near Whitebridge, at Garthbeg, and along the Gleann Liath fault, there are further minor granitic intrusions, which each differ slightly from the principal type.

The contacts of the individual members of the Foyers plutonic complex with the surrounding schists are sharp and the complex is definitely

transgressive to the schists. The line of junction is exposed in a high cliff face only in Conagleann and there the section is complicated by the presence of numerous highly-inclined sheets of tonalite, granodiorite, and granite, cutting the schists at the margin (Text-fig. 2). However, the siliceous schists at the contact dip steeply into the tonalite of the main mass—the margin of which conforms to the inward-dipping planes of the schists. The fact that the outer boundary of the complex is not influenced by changes in the level of the ground would seem to indicate that its walls are everywhere vertical or highly inclined.

The ridge of high ground (Beinn Mheadhoin—Carn na Glaice Moire), separating the two bays formed by the outcrop of the complex is, apparently, part of the roof of the intrusion ; tonalite and granodiorite outcrop on its lower slopes. The roof-schists are heavily veined with



TEXT-FIG. 2.—Horizontal section across the Foyers " Granite " Complex.

tonalite and granodiorite—the dominating vein material corresponding to and varying with the rock-type at the junction—as though the complex were continuous beneath the schists. A similar correspondence between vein types and the rock forming the margin of the complex has been found on Beinn Dubhcharaidh. The mass of siliceous augen schists around Loch Bran, much veined with granodiorite, are probably also part of the roof of the complex.

The diversion of the regional strike of the schists to conform to the margin of the complex, has, on Carn Gairbhthinn resulted in the formation of " intrusion breccias ", consisting of schist fragments in a white aplitic matrix. Elsewhere in the same locality, the schists are very heavily veined with a tonalite of slightly finer grain than the normal Foyers type.

There is no mappable aureole of contact-metamorphism round the Foyers " Granite ". The predominantly siliceous granulites would not be expected to show much contact-alteration ; fairly frequently they have a glazed appearance due to the coalescence of contiguous quartz grains. The more pelitic schists, however, develop sillimanite, andalusite, and cordierite.

Xenoliths are very abundant in the tonalite and granodiorite, but appear to be absent from the biotite-granite. They consist of larger or smaller masses of Moine schist and a series of basic dioritic inclusions : xenoliths referable to the appinite series are rare.

The schist xenoliths range from small fragments to large rafts, 12 ft. or more in length. In the Creag Mhor–Loch Scristan district there is a remarkable series of long, arcuate schist xenoliths, ranging from 12 ft. upwards in thickness and traceable in one instance for about half a mile. Creag Mhor itself consists of broad alternating ribs of schist and granodiorite. In this district the siliceous xenoliths, which are the most abundant, are found chiefly in the granodiorite, the pelitic ones in the tonalite. The siliceous schists have a glazed appearance, the pelitic schists show a high degree of contact-alteration. The contacts between the xenoliths and the enclosing rock are sharp ; sometimes the large pelitic inclusions have a marginal zone of small fragments frayed off from the parent xenolith.

The enclosing rock sometimes veins the schist rafts along their schistosity planes, splitting them up into long dyke- or sheet-like masses. The strike of the majority of the schist xenoliths conforms to the lineation of the enclosing tonalite or granodiorite, and also with that of the schists at the neighbouring margin of the plutonic complex. Lens-shaped inclusions of dark basic dioritic material are common in the granodiorite ; in the tonalite they form much larger masses. The long axes of the small inclusions conform to the lineation of the enclosing rock, as does the foliation of the larger masses. The lineation of the tonalite is always more pronounced in their vicinity.

The basic inclusions are fine-grained, dark, dioritic rocks, rich in hornblende and biotite, and with abundant sphene. Their best development is in the Loch an Ordain-Errogie district, where large masses can be seen in process of sub-division by tonalitic veins, penetrating them along their foliation. The xenoliths grade into the typical tonalite through a stage of finer-grained tonalite. Porphyroblasts of plagioclase similar to that of the tonalite, are frequent in the inclusions. Although the basic material is most abundant on the north-east margin of the complex, there is a sharp, transgressive junction between it and the schists at the contact.

Appinitic xenoliths are rare. There are a few inclusions of coarse-grained appinite in the granodiorite ; and some dyke- and sheet-like masses of fine-grained hornblende-schist found in the granodiorite near Garthbeg are probably related to the appinite series. That they are xenolithic is demonstrated by their contact-alteration and the presence in them of plagioclase porphyroblasts similar to those of the granodiorite.

Pegmatite veins cutting the Foyers complex and the surrounding Moine schists are rare ; but dykes of aplite and alsbachite are rather common, especially in the north-eastern part of the district. The complex is cut by a few small dykes of lamprophyre and microdiorite ; felsite dykes and some veins of graphic granite are common cutting the schists in the Creag nan Clag district.

The Foyers " Granite " is traversed by many crush zones and movement lines related to the Great Glen fault. The movements have evidently been spread over a long period of time ; some appear to be earlier than the Middle Old Red Sandstone. Movements earlier than the Middle Old Red Sandstone are represented by thin lines of brown microbreccia, extensive introduction of epidote and a general reddening and shattering of the rocks involved. The granodiorite, in these crush zones, changes in colour from grey to red ; the first change being an alteration from

pink to brick red in the colour of the orthoclase phenocrysts. Later all the feldspars become red in colour ; in thin section, this colour is found to be due to incipient decomposition, the crystals being crowded with brown dust and tiny sericite flakes. Individual feldspars are broken and the twinning lamellae bent, together with the development of some secondary twinning. The quartz, which shows strain shadows, is ground down to small fragments ; the biotite is bent and chloritized. Hornblende, sphene, and apatite seem to be the least affected. Epidote is introduced on a large scale, both in veins and as disseminations through the entire rock. Blue abriachanite (Heddle, 1880, p. 111) is sometimes found with the epidote. Thin, persistent lines of brownish or reddish microbreccia, usually only about 0·5 cm. in thickness, are very common, either with or without associated epidote.

The amount of microbreccia increases along some of the bigger crush-zones, until a typical crush-breccia is formed, composed of angular fragments of granitic rock in a brown matrix of finely comminuted material. This crush-breccia closely resembles in appearance, the basal breccias of the Middle Old Red Sandstone.

On Carn Dearg, the granodiorite is reduced to a greenish crush-rock. In some localities, the sheared granodiorites develop a flaggy jointing.

The movements involving the introduction of epidote and fine comminution of the rocks appear to be mostly earlier than the Middle Old Red Sandstone, which is hardly affected by them at all. Shattering of a coarser type, together with the introduction of haematite along joint faces affects both Middle Old Red Sandstone and the older rocks. This latter type of fragmentation may be due to more sudden shocks than the earlier type, which may result from prolonged but very slow shearing stresses.

(*b*) *Petrography*

The Plutonic Complex

(i) *Appinites.*—Coarse-grained hornblende-rich diorites of appinitic affinity form several small intrusive masses in Knockie Forest. They consist of oligoclase-andesine largely altered to sericite and calcite, subsidiary orthoclase, very abundant green hornblende in large but poorly-shaped crystals, interstitial quartz and accessory sphene, iron ore, and rather abundant apatite. A specimen from Loch Kemp contains a little microcline in addition to orthoclase. At Loch Knockie, the rock becomes finer in grain as it is traced eastward, but is otherwise of a similar type. There are also a few minor intrusive masses of hornblende-rich diorite in Gleann Liath, where they cut the siliceous schists surrounding Loch Bran. In all these rocks, epidote is found abundantly both disseminated through the rocks and as a coating on joint planes..

(ii) *Tonalite.*—The Foyers Tonalite, Analysis (1), is a coarse-grained, grey, hornblende-biotite-quartz-diorite, composed of oligoclase-andesine (An_{30}), subsidiary orthoclase and quartz, biotite and subsidiary hornblende, with accessory brown sphene, colourless apatite, and black iron ore. The plagioclase forms large mutually interfering plates ; the larger crystals are zoned from cores of sodic labradorite (An_{55}). Wart-like

myrmekitic intergrowths of quartz and plagioclase are commonly found on the margins of the orthoclase. The chief dark mineral is biotite,

	(1)	(2)	(3)
SiO_2 . .	54·95	60·77	74·72
Al_2O_3 . .	20·57	16·44	14·17
Fe_2O_3 .	1·87	1·77	0·63
FeO . .	4·68	3·92	1·17
MgO . .	2·68	2·71	0·36
CaO . .	4·82	4·44	0·68
Na_2O . .	4·84	3·73	3·58
K_2O . .	2·75	3·39	3·84
H_2O + .	0·72	1·53	0·33
H_2O − .	0·13	0·05	0·07
CO_2 . .	none	none	none
TiO_2 . .	1·09	0·95	0·22
P_2O_5 . .	0·43	0·25	trace
MnO . .	0·26	0·26	trace
	99·79	100·21	99·77

(1) Tonalite. Foyers plutonic complex. From old quarries in field immediately south of Wester Aberchalder Lodge.
Analyst: W. H. Herdsman.
(2) Tonalitic granodiorite. Foyers plutonic complex. Dell Marsh quarries, ½ mile S.W. of Upper Falls of Foyers.
Analyst: W. H. Herdsman.
(3) Biotite-granite. Foyers plutonic complex. Flank of Creag a'Chlia-bhain, about ¼ mile S.E. of Easter Aberchalder Farm.
Analyst: W. H. Herdsman.

strongly pleochroic from pale yellow to dark brown. The hornblende, X = yellowish green, Y = green, Z = green with bluish tinge, is frequently twinned. Small crystals of biotite and hornblende are often enclosed in the feldspar plates. Brown sphene, in lozenge-shaped crystals up to 2 mm. in length, is an abundant accessory.

A finer-grained tonalite veining the schists at Carn Bhreabaig and Carn Gairbhthinn is similar, but richer in hornblende. Biotite-tonalite, poor in hornblende and sphene, and more quartzose than the type rock, veins the schists between Whitebridge and Loch Kemp.

(iii) *Granodiorite.*—The type granodiorite, Analysis (2), is a coarse-grained, grey, hornblende-biotite-granodiorite with prominent phenocrysts of pink perthitic orthoclase averaging half an inch in length. The rock consists of quartz, oligoclase, orthoclase, hornblende, and biotite with accessory sphene, apatite, and black iron ore. Some of the larger plagioclase crystals are zoned from cores of sodic andesine (An_{35}). The orthoclase phenocrysts often enclose blebs of quartz and small plagioclase crystals, marginal wart-like myrmekitic intergrowths are common. The biotite and hornblende resemble those of the tonalite; the cores of the hornblende crystals are sometimes sieved with quartz. The biotite contains inclusions of zircon with faint pleochroic halos.

Modifications of the principal type are found in the satellite intrusions between Lochs Knockie and Kemp.

The Cnoc Carrach type differs in its larger phenocrysts (1–2 in.) of

orthoclase and also of plagioclase, and in its rather more quartzose character.

The Meall nan Aidhean granodiorite, which often veins the siliceous schists, is finer in grain, richer in quartz than the type-rock, and the biotite flakes are strongly aligned. There are numerous small, pink orthoclase crystals. Sphene is not very prominent ; hornblende is always subsidiary to biotite and sometimes absent ; in the latter case, orthite appears. The plagioclase is often strongly zoned, from cores of calcic oligoclase (An_{28}) through zones of oligoclase-andesine (An_{30}) and calcic oligoclase (An_{25}) to oligoclase (An_{20}).

The granodiorite-porphyry, found in dyke-like masses near Loch Kemp, is finer-grained than any of the preceding types. It is a grey, granulitic rock, more quartzose than the normal granodiorite and with large phenocrysts of pink perthitic orthoclase. In thin section, the latter are found to contain inclusions of quartz, plagioclase, apatite, sphene, biotite, and hornblende, and their margins are embayed against the surrounding finer-grained minerals.

(iv) *Granites.*—The Foyers Granite, Analysis (3), is a highly quartzose, non-porphyritic, pink, biotite-granite, finer in grain than the tonalite and granodiorite. It is composed of abundant quartz, perthitic orthoclase, microcline-microperthite and sodic oligoclase (An_{15}) with very subsidiary brown biotite and sparse accessory hornblende, sphene, apatite and black iron ore. The texture is granulitic, the feldspars being subhedral or anhedral ; the larger feldspars usually enclose blebs of quartz and smaller feldspars. The small flakes of biotite enclose zircon (with pleochroic halos) and apatite.

A small granitic intrusion at Garthbeg differs in the virtual absence of dark minerals, only very sparse biotite and a little magnetite being present. On the Gleann Liath fault zone, near the Falls of the Farigaig, there are several small outcrops of a very badly sheared, highly quartzose biotite-granite, coarser in grain than the type rock. The summit of Carn Dearg (near Foyers) is composed of a finer-grained pink granite, also very badly sheared. Medium grained, biotite-granites, with more abundant biotite and a faint lineation are seen in isolated outcrops in the Rivers Fechlin and Brein at Whitebridge. Hornblende is absent in all these rocks.

Contact-altered Moine Schists

It has already been pointed out that the siliceous granulites both at the margin of the plutonic complex and forming xenoliths within it, show very little contact-alteration (pp. 255–6). The semi-pelitic schists are somewhat variable in their reaction. Some xenoliths are apparently unaltered. Some of the semi-pelitic schists on the margin of the complex at Loch an Ordain, however, have developed a little cordierite and the biotite has a foxy red " hornfels " colour. Near Loch Kemp, the texture of the semi-pelitic schists becomes more nearly equigranular, though the red biotite still retains its schistose alignment, and cordierite, andalusite, and sillimanite are developed in the rock. The sillimanite is found both as felted masses of small needles associated with the biotite folia and as larger blades, visible in hand specimen.

In Conagleann, the muscovite-biotite-injection-gneiss in contact with the tonalite develops a little cordierite, sillimanite, and andalusite; the sillimanite needles are sometimes visible macroscopically. The cordierite is altered to pinite and is usually associated with the biotite.

Andalusite, altered to sericite, but still showing a chiastolite-like cross of graphite inclusions, occurs in greenish mica-schists near Knockie boathouse. These schists may belong to the Glen Doe Series. A black andalusite-schist, in which numerous andalusite crystals, about a quarter of an inch in length, are prominent on weathered surfaces, is found interbedded with glazed siliceous schists at Lochan a'Chinn Mhonaich, and also near Loch Bran. It consists of abundant biotite (pleochroic from pale yellow brown to foxy red), which still retains its original foliation, subsidiary muscovite, quartz, cordierite, andalusite, and sillimanite, with accessory tourmaline, graphite, and black iron ore.

Foliation is lost in the black hornfelses which occur as long lenticular inclusions in the tonalite between Lochs Kemp and Scristan. One of these hornfelses closely resembles the hornfelsed pelitic Moine schists described from the Ross of Mull (Bosworth, 1910, p. 376; Bailey and Thomas, 1925, pp. 49–55). It is an andalusite-cordierite-sillimanite-hornfels; the sillimanite needles reach a length of three-quarters of an inch and are prominent on the weathered surfaces. The hornfels is a heavy

	(4)	(5)	(6)	(7)
SiO_2	52·44	51·73	56·98	62·92
Al_2O_3	21·97	20·85	15·82	17·1
Fe_2O_3	3·04	1·73	0·78	0·6
FeO	4·18	5·62	5·26	4·3
MgO	1·60	3·78	4·37	3·2
CaO	5·94	5·94	6·23	2·7
Na_2O	4·96	3·96	3·28	3·7
K_2O	1·68	2·62	3·61	3·0
H_2O+	0·72	0·78	1·58	0·7
H_2O-	0·16	0·27	0·12	0·1
CO_2	none	none	none	no
TiO_2	2·66	1·80	1·12	0·9
P_2O_5	0·23	0·63	0·32	0·1
MnO	0·13	0·16	0·34	0·1
	99·71	99·87	99·81	99·9

(4) Feldspathized schist inclusion in tonalite. From a locally derived block, Loch Garth shore, Migovie.
Analyst: W. H. Herdsman.

(5) Basic dioritic inclusion in tonalite. Loch an Ordain.
Analyst: W. H. Herdsman.

(6) Basic inclusion in tonalitic sheet cutting schists. Torr Shelly quarry, Errogie.
Analyst: W. H. Herdsman.

(7) Part of the tonalitic sheet enclosing xenolith (6). Torr Shelly quarry, Errogie.
Analyst: W. H. Herdsman.

black rock containing abundant red biotite with a decussate habit, muscovite, sillimanite, andalusite, cordierite, abundant specks of iron ore, and a little green spinel. The sillimanite is found both as large bladed crystals and as tufts of small needles. The cordierite forms a mosaic,

rarely showing sector twinning and with no yellow halos around inclusions. The andalusite forms large crystals, devoid of inclusions.

Streaked green and white hornfelses derived from calc-silicate granulites have been found as xenoliths only in veins of granodiorite on Carn na Glaice Moire and the tonalite of the intrusion " breccia " on Carn Gairbthinn. They consist principally of granulitic quartz and calcic oligoclase (An_{25-30}), with small crystals of hornblende (X = yellow, Y = yellow-green, Z = dark blue-green), and faintly blue-green poikiloblastic diopside, together with variable amounts of zoisite, sphene, biotite, apatite, pyrite, and poikiloblastic garnet.

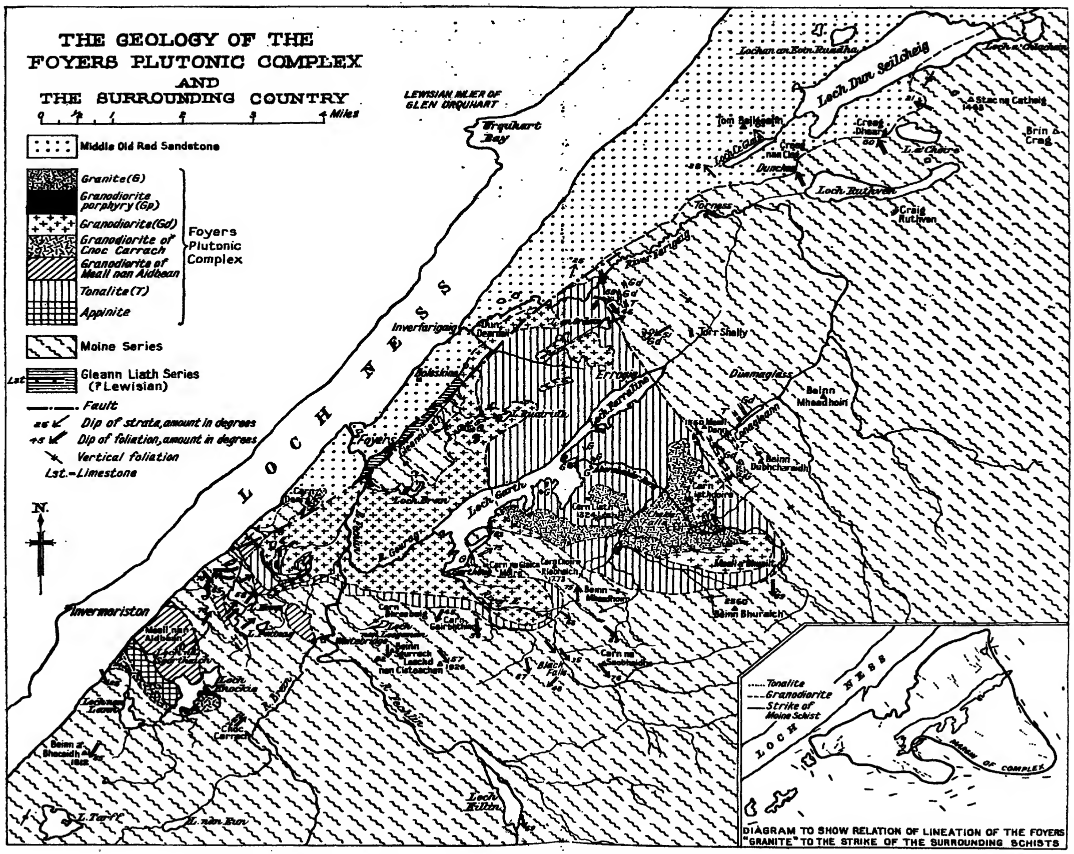
An epidiorite xenolith enclosed in the tonalite and veined with white aplite is interesting in that the hornblende of the epidiorite is found to be replaced by biotite as the vein is approached. The aplite consists of quartz and andesine, with subsidiary orthoclase and biotite ; the change from hornblende to biotite in the epidiorite takes place quite sharply about a quarter of an inch from the contact. The green hornblende of the epidiorite occurs both in compact and poikiloblastic crystals and both types are perfectly pseudomorphed by biotite (pleochroic from pale brown to dark reddish-brown). There is also a slight increase in the amount of apatite present in the rock as the vein is approached.

Feldspathized Schists

Very rarely, small xenoliths of feldspathized schist have been found in the tonalite. They are obviously derived from semi-pelitic Moine schist, but are enriched both in biotite and in feldspar (Analysis (4)). They consist of aligned, lozenge-shaped oligoclase crystals, with subsidiary orthoclase and abundant brown biotite with accessory sphene and black iron ore. The sphene often surrounds the granules of iron ore, and the two minerals are usually concentrated along particular layers. The rock is permeated by small veinlets from the enclosing tonalite. In Torr Shelly quarry, where these inclusions occur in a tonalitic sheet cutting the schists, together with numerous basic enclaves, they often have a selvage of large, lustrous biotite plates.

Basic Dioritic Inclusions

The basic enclaves, which are found so abundantly in the tonalite and rather less abundantly in the granodiorite, are all of dioritic composition, rich in biotite and hornblende, with light brown sphene as a common accessory. Porphyroblasts of plagioclase, similar to those of the tonalite and usually elongated parallel to the foliation of the enclaves, are of common occurrence. The xenoliths vary somewhat in coarseness of texture, usually have a marked foliation and sometimes show a banding of light and dark components. The hornblende and biotite resemble the types found in the tonalite and granodiorite. Apatite found both as numerous fine needles and stouter prisms, is a very common accessory. It is sometimes of a smoke-blue colour, due to the presence of numerous rod-like inclusions which lie parallel to the length of the crystal and sometimes show a zonal arrangement. The texture of the enclaves is typically poikiloblastic. They are obviously being made over into varieties



TEXT-FIG. 3.—Map of the Geology of the Foyers Plutonic Complex and the Surrounding Country.

[*Facing p. 260.*

resembling the enclosing tonalite and granodiorite, and some textural peculiarities of the latter rocks may be due to their incorporation.

The finer-grained type of enclave (Analysis (6)) is well seen in the Torr Shelly outcrop, where they are found in a sheet of tonalite cutting the schists. The tonalite here is slightly richer in quartz than the type rock. The xenoliths are dark, compact, but slightly foliated rocks, with sparse porphyroblasts of oligoclase. They consist of granoblastic quartz, orthoclase, and oligoclase, with abundant hornblende and biotite, and accessory sphene, apatite, and iron ore. Myrmekitic intergrowths have not been observed, but blebs of quartz are found in the feldspars. The sphene is sometimes moulded on the iron ore. These xenoliths usually show sharp junctions with the enclosing tonalite, but in places pass into a streaky, finer-grained tonalite, richer in dark minerals than the normal rock (Analysis 7).

The coarser-grained basic inclusion (Analysis 5) shows lustrous plates of biotite and blades of hornblende in hand specimen, as well as numerous brown sphenes. The rock consists of oligoclase-andesine, hornblende, and biotite, with accessory apatite, sphene, and iron ore. Sphene usually forms lozenge-shaped crystals, but also rims the iron ore. The texture is typically poikiloblastic. Hornblende is sometimes moulded onto biotite ; biotite may be enclosed in the hornblende. Small feldspars have been observed enclosed both in biotite and hornblende, and also in the larger sphenes. Quartz is absent from the analysed rock ; in none of the enclaves is it more than a sparse accessory.

Another xenolith (south-east of Loch an Ordain) contains lighter-coloured " eyes ", composed of sodic plagioclase and skeletal sphene, elongated parallel to the foliation of the rock.

These basic dioritic enclaves seem to correspond with the diabrochites of Dunn (1942, pp. 231–8), which he defines as schistose rocks which have recrystallized under the influence of migrating solutions. They differ from migmatites in that the added material is not obviously granitic. Dr. D. L. Reynolds (1944, p. 244) has adopted the term for " rocks which resulted from the basification and desilication of hornfelsed sediment, dependent on the fixation of material expelled during granitization ", and has shown that Fe and Mg are driven out from loci of granitization to the outer zones of replacement, where they are found in rocks enriched in hornblende and biotite. It should be pointed out that in the Foyers plutonic complex, no transitions from the basic inclusions to ordinary Moine schists have been found, and that if the basic enclaves do represent relics of basified schist, the process must have taken place at depth, prior to the intrusion of the complex into its present position.

VI. The Middle Old Red Sandstone

The Middle Old Red Sandstone in the Foyers district forms a narrow strip bordering Loch Ness and ending at Carn Dearg. Northward from Loch Dun Seilcheig the outcrop rapidly broadens and has yielded fossils of Middle Old Red Sandstone age (Peach, 1923, pp. 65–76 ; Horne, 1914, pp. 66–8).

In the Foyers-Loch Dun Seilcheig district, the Middle Old Red Sandstone consists predominantly of conglomerates with subsidiary breccias,

arkoses, sandstones, and shales. The breccias are restricted to the base of the formation, which rests with marked unconformity on the older rocks.

The unconformity is well exposed in a number of localities—Foyers limestone quarry, Dun Deardail, Dunchia Hill, and Creag Dhearg. The junction is exposed at intervals for about three-quarters of a mile on Dunchia Hill, where the Old Red Sandstone forms an escarpment above the Moine schists. The north-east end of Dunchia forms the magnificent cliff of Creag nan Clag, on the face of which the junction is laid bare for 200 yards. Here the flaggy Moine schists form an irregular surface on which rest the basal breccias. At one end of the cliff the normally vertical schists are folded into a monocline, the horizontal limb of which rests directly beneath the basal breccias. The lowest part of the latter consists of broken but undisturbed schist fragments, in a sparse red gritty matrix, obviously derived from the underlying horizontal schists. The basal breccia is everywhere of this extremely local derivation, being composed of angular schist fragments where it overlies the Moine Series, of granodiorite or granite where it rests upon the Foyers plutonic complex, and of green mica-schists and limestone fragments where it overlies the Gleann Liath Series. In the last area, the basal breccia is an extremely well compacted green rock, almost schistose in places. It passes up rapidly into more typical grit and conglomerate.

The basal breccia is succeeded by rudely stratified coarse conglomerates, composed of rounded but poorly sorted boulders of local Moine schists (including a few soft, mica-rich varieties), and less commonly rocks of the Foyers plutonic complex. In the Dunchia—Creag Dhearg district, boulders of pink felsite are extremely common. Thin, arkosic grits and sandstones are interbedded with the conglomerates. The arkoses are hard, red in colour, and composed of angular fragments, with subsidiary coarser bands carrying pebbles of granitic types from the Foyers plutonic complex. They contain fresh, nearly perfect orthoclase crystals derived from the Foyers granodiorite as well as numerous flakes of biotite. The thin-bedded red sandstones in the Loch Ce-glais district are very rich in muscovite derived from the Moine schists. The bedding planes show ripple marks and more irregular puckerings ; some surfaces show very perfect suncracks. The sandstones are unfossiliferous. Green and purple shales are exposed in a small quarry at Castle Kitchie. The shales show rain prints and also tiny, crowded raised points of uncertain origin. A fragmentary fossil fish was found in these shales, which may represent a diminished lateral extension of the Nairnside fish-bed represented at Lochan an Eoin Rudha to the north-east.

The basal breccias evidently represent local scree formations resting on the rocks from which they were derived. The freshness of the fragments indicates that they must have accumulated under climatic conditions in which chemical weathering was at a minimum. Later, shallow lakes must have formed, in which the sandstones overlying the breccias were deposited. These lakes must have been liable to frequent drying-out when the sun-cracked and ripple-marked surfaces were formed. Their character is well seen at Dun Deardail, where the basal breccias pass up into a few feet of chocolate sandstone, above which come more breccias.

The latter, composed of fragments of the Foyers granodiorite, rest on the irregularly folded sandstones and evidently represent screes which slumped onto the sandstones whilst they were still unconsolidated.

The conglomerates seem to be torrential deposits, rapidly accumulated not far from the sources of their components—large blocks of soft mica-schist are found in them. The sandstones developed higher in the series, exposed near Dores, north-east of the district under discussion, indicate the subsequent oncoming of more persistent lacustrine conditions.

The Middle Old Red Sandstone has been much involved in the Great Glen Movements. At Tom Bailgeann, it is still possible to separate the boulders in the conglomerates from their matrix; the boulders are, however, frequently sheared across, both with and without lateral movement. Lines of movement, cutting straight through the larger boulders, may be often traced on the crags above Loch Ce-glais. At Foyers, however, the conglomerates have been so intensely compacted, that it is no longer possible to separate pebbles from matrix; the whole has been welded into an intensely hard rock. The associated grits, arkoses, and breccias are similarly hardened and compacted.

In the Foyers district, the Middle Old Red Sandstone is also traversed by numerous shatter belts, along which the rocks are extensively broken, and stained with haematite; quartzite pebbles in the conglomerates crumble into small fragments on handling, in these zones.

VII. The Great Glen Fault

Professor W. Q. Kennedy (1946, pp. 41–72) interprets the Great Glen Fault as a wrench fault with a lateral displacement of 65 miles, and believes that the Foyers and Strontian "granite" complexes are part of a single original mass. The present detailed study of the Foyers complex has shown its likeness to the Strontian mass in many particulars, but has also revealed some differences.

The Foyers complex resembles that of Strontian (Kennedy and MacGregor, 1932, pp. 105–119) in the concentric arrangement of its members, the similarity of its tonalite, granodiorite, and granodiorite-porphyry, the presence of basic inclusions and long, strip-like xenoliths of Moine schist, and in the regional deflection of the strike of the schists surrounding the complex. The internal relationships of the various members of the two complexes are also alike. The appinites found at Strontian are of more numerous types than those of Foyers, but the Foyers appinites can be matched with Strontian varieties.

The Foyers granite, however, differs from that of Strontian in carrying small amounts of hornblende. No contact-metamorphism of the schists has been recorded at Strontian, whereas a high degree of contact-alteration is found in some of the pelitic schists at Foyers. Both complexes cut injection complexes of Moine schists of similar types, but no inliers resembling that of Gleann Liath are recorded from the Strontian district.

In conclusion, I wish to express my warmest thanks to Professor Arthur Holmes and Dr. Robert Campbell for much valuable assistance during

this research; to the Carnegie Trust for a grant toward the cost of chemical analyses; and to Mr. Anderson, Inverfarigaig, who rendered me much assistance in the field.

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Explanation of Plate XV

FIG. 1.—Basic dioritic xenoliths enclosed in the tonalite of the Foyers " Granite " complex. Shore of Loch Farraline at Errogie.

FIG. 2.—" Intrusion breccia " of schist fragments on the margin of the Foyers " Granite " complex. Summit of Carn Gairbhthinn.

The Faunal Sequence in the Kent Coalfield

By C. J. STUBBLEFIELD [1] and A. E. TRUEMAN

A SUMMARY of the stratigraphy of the Coal Measures in the Kent Coalfield was given by H. G. Dines in 1933, accompanied by notes on the fossil flora by R. Crookall and on the fauna by C. J. Stubblefield. It was shown that the Coal Measures could be divided into a Lower or Shale Division, some 700 feet thick, consisting mainly of shales with some thick coals, and an Upper or Sandstone Division, about 2,100 feet thick, consisting mainly of sandstone with a few mostly impersistent coal seams, except in the highest part where again there are shales with coals (Dines, 1933, p. 22); the dividing line was taken at the base of a sandstone usually about 100 feet below the Millyard Seam. Recently the correlatable seams in the coalfield have been designated by means of numbers in downward succession and seams numbered 1–6 lie in the Sandstone Division, and numbers 7–14 in the Shale Division (Dines, 1945). R. Crookall regarded the Upper or Sandstone Division as representing the Staffordian and part of the Radstockian series, while the Shale Division he referred to the Yorkian (Text-fig. 1).

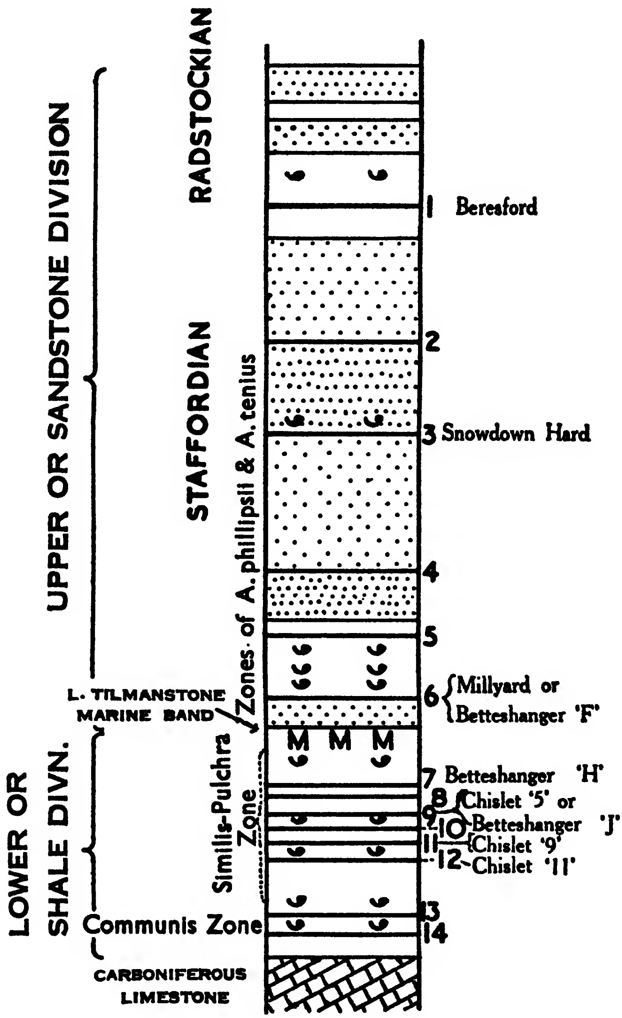
The faunal evidence suggested the presence of the Pulchra, Phillipsii, and Tenuis Zones. The *Anthraconauta* and *Anthraconaia* [2] faunas of the two latter zones were reasonably well developed, although inadequate for the fixing of a precise boundary. The faunas from the lower horizons were unsatisfactory, being generally badly preserved and consisting in the main of long ranged forms of *Anthraconaia*, and of small species of *Anthraconauta* and *Naiadites* but the record of *Carbonicola* by Bolton (1915, pl. ix) had led to the conclusion that some horizon below the Tenuis and Phillipsii Zones was represented in Kent (Trueman, 1933).

Marine bands have been recorded from several boreholes in the Kent Coalfield, namely at Walmestone, Mattice Hill, Barfrestone, Ripple, and Oxney (Bolton, 1915), and at Tilmanstone (Stubblefield, 1933). Most of these marine occurrences were considered to be of the same general horizon in the Geological Survey 1933 publications, and in 1945 were shown by Dines to occur (with the exception of one of the two bands recorded at Barfrestone) between the Kent Seams Nos. 6 and 7. The possibility exists, however, of another marine horizon being proved in Kent at a lower horizon than those encountered at Tilmanstone, for Bolton (1915, pp. 669, 672) recorded from Ripple Borehole strata which are described in a manuscript dated 1913 (now in the possession of the Geological Survey) as "dark shale with small *Lingula mytiloides* and *Anthracomya laevis* var. *scotica* at 2,959 feet 3 inches". The specimens have not been available for re-examination but the horizon is in the roof measures of the coal at 2,963 feet recently considered by Dines (1945) to be the Kent No. 12 Seam. Neither marine fossils nor *Lingula* have been found at this level elsewhere in the coalfield and the record requires

[1] Published by permission of the Director of the Geological Survey and Museum.

[2] This name replaces *Anthracomya* formerly used for these shells (Trueman and Weir, 1946).

verification before it is accepted. If it is correctly recorded, it affords evidence of the existence of a marine band either near the base of the



TEXT-FIG. 1.—Generalized Section of the Coal Measures of Kent to illustrate the probable zonal classification. The seam numbers on the right-hand side are those given by Dines (1945), from which publication this diagram is adapted. Scale 600 feet to 1 inch.

Similis-Pulchra Zone or perhaps even in the underlying Modiolaris Zone.

At Tilmanstone, two marine horizons were observed, which are here referred to as the Tilmanstone Marine Beds. These were 57 feet apart

and a seat-earth occurred a few feet below the base of the upper bed; this upper horizon was 96 feet below the Kent No. 6 Seam (Text-fig. 3). On the limited evidence available in 1933 it was suggested that both these Tilmanstone horizons were in the Phillipsii Zone and therefore represented a marine incursion later than any known elsewhere in the Coal Measures of Britain (Stubblefield, 1933, p. 75). If this interpretation is correct it would follow also that they are higher than any known marine band in North-west Europe and that the horizons are not represented by marine strata even in the neighbouring Pas de Calais Coalfield (Trueman, 1946, p. lxxiv).

Jongmans has recently given a summary of the palæontological evidence concerning the correlation of the Kent Coal Measures and has suggested that the marine bands in question (the Tilmanstone Marine Beds) may not be so high as had been supposed. Basing his conclusions largely on the floral evidence he regards them as equivalent to the Rimbert Marine Band of northern France and the Aegir of the Ruhr (Jongmans, 1940, p. 35).

At Barfrestone, which is about 1⅛ miles west of Tilmanstone, two marine horizons were recorded by Bolton; these, at 2,775 feet and 3,138 feet below surface (see Text-fig. 3), were some 360 feet apart, with the coal now termed Kent No. 6 Seam (Dines, 1945), presumably the equivalent of the Millyard Seam of Snowdown Colliery, lying approximately midway between them. The lower horizon is probably the lower of the two Tilmanstone horizons, but the upper horizon has no marine parallel elsewhere in the coalfield (or in any British coalfield). The association of fossils recorded by Bolton (1915, pp. 662, 675) as *Anthracomya laevis* var. *scotica* with *Productus longispinus* in a "bastard cannel" suggests that the marine nature of this higher horizon requires confirmation. In the Bolton 1913 manuscript the anomalous fossil is recorded merely as "spines of *Productus*"; it is now thought possible that they were fish spines. There is thus good evidence of only one group of marine bands in Kent, the Tilmanstone Marine Beds and their equivalents.

In recent years much new information has been obtained concerning the faunal sequence in the Kent Coalfield, particularly from operations at the north-west end in the workings of Chislet Colliery. This evidence is of such importance that it appears desirable to record the conclusions to which it leads. Opportunity has also been taken to re-examine the specimens from Tilmanstone and other sinkings and borings on which the opinions concerning the faunal sequence had been based.

The Communis Zone

Evidence of the Communis Zone (formerly known as the Ovalis Zone) has been obtained from two underground boreholes at Chislet in the strata between the Kent Seams Nos. 13 and 14 of Dines' 1945 correlations (Text-fig. 2). In both these boreholes the fauna indicating this zone is preserved in an arenaceous micaceous mudstone and is especially noticeable for the large size of the majority of the lamellibranchs, which include :—

Carbonicola cf. *ovalis* (Martin).
Carbonicola cf. *communis* Davies and Trueman s.l.
Carbonicola cf. *declivis* Trueman and Weir (1946, pl. ii, fig. 29).
Carbonicola cf. *polmontensis* Brown sp. (Trueman and Weir, 1946, pl. iii, fig. 19).
Carbonicola cf. *bipennis* Brown sp. (= *C. binneyi* Wright).
Carbonicola cf. *browni* Trueman and Weir (1946, pl. i, fig. 22).
Carbonicola cf. *crista-galli* Wright.
Carbonicola sp. of *pectorata* Wright type.
Anthraconauta cf. *subovata* Dewar.
Naiadites flexuosus Dix and Trueman.

This fauna is a clear indication of the presence of the Communis Zone, probably of the higher part of the zone. The absence of *Carbonicola pseudorobusta* Trueman, a common species in many areas where large Carbonicolas occur in this zone, is interesting but is in accord with the frequent experience in this zone in such other southern coalfields as South Wales and Somerset.

The Communis Zone fauna ranges through approximately 30 feet of strata in one of the Chislet boreholes and 20 feet in the other. The distance from the top of the Carboniferous Limestone is not definitely known since neither borehole was deep enough to pass into that limestone. Stodmarsh Borehole, made in 1910, is but a fraction over a mile to the south-east of one of these Chislet holes and from sandy binds at 1,984 feet, 69 feet above the top of the Carboniferous Limestone, Bolton (1915, pp. 653, 683, pl. ix, fig. 10) recorded specimens of *Carbonicola*.[1] The position of these shells is also between Kent Seams Nos. 13 and 14 of Dines' 1945 correlation of the Stodmarsh section (Text-fig. 1). From a horizon 39 feet above the top of the Carboniferous Limestone at Woodnesborough " an undoubted example of *Carbonicola* " was also recorded by Bolton in his 1913 manuscript, as coming from a depth of 2,594 feet (see also Bolton, 1915, p. 657). It is concluded therefore that the Chislet fossils are from within close distance of the local base of the Coal Measures.

The absence of Millstone Grit from those parts of the Kent Coalfield where the basal strata of the Upper Carboniferous have been penetrated has long been remarked. If it is concluded, however, that the Communis Zone faunas at Chislet lie at only a short distance above the base of the Coal Measures, it must follow that the Lenisulcata Zone is either unrepresented or is extremely thin.

In one of these underground boreholes at Chislet the Communis Zone fauna occurred about 30 feet below a horizon with other non-marine shells, which included *Naiadites ?* and fairly large but incomplete

[1] This " *Carbonicola acuta* " (? = *C. crista-galli* Wright) was figured by Bolton (1915) as from a depth of 1,984 feet at Stodmarsh Borehole. In the 1913 Bolton manuscript, previously referred to, and also in the Malcolm Burr Collection register, the depth is given as 2,071 feet. The Stodmarsh Borehole was commenced at 87 feet O.D., which figure is the difference between the two recorded depths. In his paper, Bolton usually, but not invariably, gave depth figures as feet below sea-level. At Stodmarsh the Carboniferous Limestone was entered at 2,140 feet below the surface (2,053 feet B.O.D.).

Anthraconaia. It is impossible to decide the horizon of this fauna but it is likely to represent the Modiolaris or the Similis-Pulchra Zone. If the latter is the case, it may be noted that no lamellibranch evidence of the Modiolaris Zone has been met with at any locality in Kent [1] and the possibility that a non-sequence or an unconformity may occur within these strata must be recognized. The record of *Lingula mytiloides* at Ripple Borehole already referred to, however, may indicate the presence of the Modiolaris Zone, since it relates to strata newer than the Communis Zone (Kent Seams Nos. 13 and 14).

The Modiolaris Zone is very thin in several parts of Britain but no evidence of a break within this part of the sequence appears to have been noted anywhere else in northern Europe. The local absence or very great reduction of the Modiolaris Zone is therefore surprising. In the neighbouring coalfield of the Pas de Calais, although the lower part (Ammanian) of the Coal Measures is considerably thinner than in other coalfields of northern France and Belgium, the Modiolaris Zone appears to be present.

The next fauna at Chislet occurs at about 100 feet higher, that is, a few feet below the Chislet No. 11 Seam (= Kent No. 12 Seam [2]) and includes a specimen of *Naiadites* cf. *productus* (Brown). This, however, also affords somewhat indefinite evidence of horizon, and though it is most likely to be the Modiolaris or Similis-Pulchra Zone, its precise position is not clear.

The Age of the Upper Part of the Shale Division

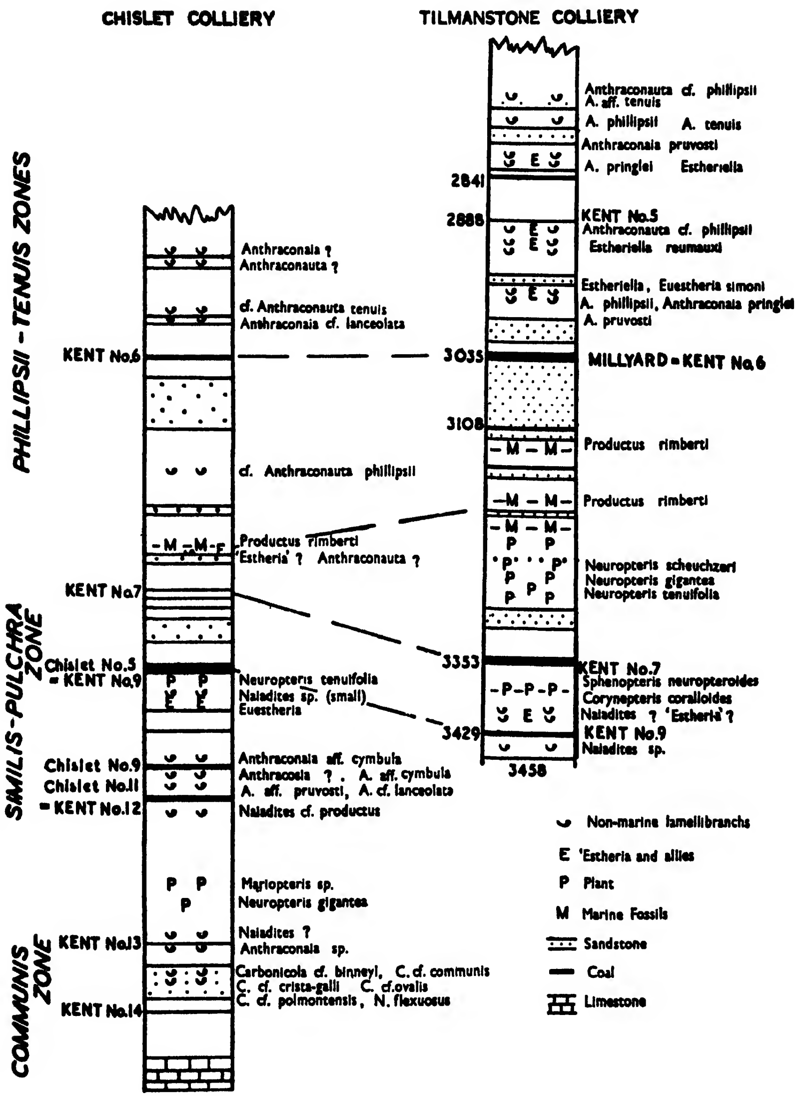
The specimens from the horizons immediately succeeding, both at Chislet and at Tilmanstone, are generally small and, except at a few horizons, are poorly preserved. They consist almost entirely of specimens of *Naiadites*, *Anthraconauta*, and a few elongated forms of *Anthraconaia* with the general characters of *A. pruvosti* (Tchernyshev) and *A. lanceolata* (Hind). These latter forms are particularly difficult to use for zonal purposes for they tend to occur at various horizons from the Upper Similis-Pulchra to the Tenuis Zone and, indeed, closely similar forms are characteristic of the succeeding Prolifera Zone. The chief characteristic of these shales, therefore, is the almost complete absence of shells which could be referred to *Carbonicola* or to the related genus *Anthracosia*, and the absence of any characteristic and abundant examples of *Anthraconauta phillipsii* (Williamson).

As already noted, *Naiadites* cf. *productus* (Bc2243) has been identified from 10 feet below the Chislet No. 11 Seam (= Kent No. 12).

Above the Chislet No. 11 Seam there occurs a very distinctive fauna

[1] The shell figured as *Anthracomya modiolaris* by Bolton (1915, pl. ix, fig. 21) is an *Anthraconauta*, and is from a higher horizon above Kent No. 1 Seam.

[2] If the observation, made in the explanation of Text-fig. 2, is correct concerning the new correlation of Kent No. 7 Seam in the north and centre of the coalfield it is conceivable that Chislet No. 11 Seam is higher in the sequence than the coal at Ripple at 2,963 ft. (see p. 266).



TEXT-FIG. 2.—Sections at Chislet Colliery and Tilmanstone Colliery. The Chislet section is composite and based on underground boreholes; the Carboniferous Limestone position is inserted from the evidence of Stodmarsh Borehole. The Kent Seam numbers used in the two sections are taken from Dines' 1945 Report, but the Chislet composite section shown above incorporates evidence additional to that available in 1945. It will be seen that the correlation of Chislet No. 5 Seam with the coal at Tilmanstone at 3,353 ft. now appears more likely than that shown by the correlation lines joining the seams called Kent No. 7. The plant identifications are by Dr. R. Crookall. Scale 100 feet to 1 inch.

which includes a surprising abundance of Anthraconaias of the *A. pruvosti*-*A. lanceolata* types. Although *Anthraconauta* may occur it is difficult to distinguish it very definitely from the small forms of *Naiadites*. There is no doubt that some of these naiaditiform shells do belong to the genus *Naiadites* and it would be difficult to establish that any of them are *Anthraconauta* of the *phillipsii* group.

Other fossils at a slightly higher horizon (midway between Chislet No. 9 or Kent No. 11 and Chislet No. 11 Seams) include an incomplete specimen which is very doubtfully referred to *Anthracosia* cf. *aquilina* (Text-fig. 2). This is associated with *Naiadites* sp. and *Anthraconaia* cf. *cymbula* (Wright). There are no typical *pruvosti*-like forms and the Anthraconaias appear to have the rounded lower border which is characteristic of shells of the Similis-Pulchra Zone rather than of Anthraconaias which occur in the Phillipsii Zone.

These faunas from the interval between the Chislet No. 9 Seam and just below the Chislet No. 11 Seam therefore appear to represent the Similis-Pulchra Zone, and if the *Anthracosia* is correctly identified, they indicate that the horizon is Lower Similis-Pulchra. More evidence is required, however, before this can be regarded as demonstrated. Nevertheless, the evidence at Chislet is sufficient to indicate that these parts of the sequence represent the Similis-Pulchra rather than the Phillipsii Zone.

The specimens from Tilmanstone which were recorded in the papers referred to (Dines, Crookall, and Stubblefield, 1933) have been re-examined. One shell which was recorded as "cf. *Anthraconauta phillipsi*" (Ba3480) from immediately below Kent No. 9 Seam is now regarded as *Naiadites* sp., while the "? *A. phillipsi*" (Ba3474) from the roof of Kent No. 9 may also be *Naiadites*, but the specimen is too poor for more definite determination. It is concluded that these two specimens do not justify the conclusion that the Phillipsii Zone extends below the marine bands at Tilmanstone. This is supported by the evidence of the more abundant material from Chislet, from what is apparently a similar stratigraphical horizon (see Text-fig. 2).

Additional evidence bearing on horizon is derived from Bolton's Mattice Hill Borehole specimen from 1,377 feet (this depth is scratched on the specimen) figured as *Naiadites carinata* (Bolton, 1915, pl. ix, fig. 18); this specimen has been renamed *N.* cf. *producta* (Stubblefield, 1933, p. 71) and it occurred at a depth close to that of the marine band in that borehole.

Bolton also recorded *N. carinata* from Walmestone Borehole (1915, p. 654); his 1913 manuscript states that this came from a depth of 1,917 feet below surface; this is from immediately below the coal at 1,910 feet which is now (Dines, 1945, p. 20) termed Kent No. 9 Seam (that is the equivalent of Chislet No. 5).

Specimens from the roof of the I Seam at Betteshanger Colliery (which according to Dines, 1945, is a seam between Kent No. 7 and Kent No. 9 and in fact may be Kent No. 8) include "a rather naiaditiform shell with a long anterior end" (Trueman *in* Stubblefield, 1933, p. 76). This shell (De761) has been re-examined and is certainly a *Naiadites*; the previous record of the associated "*Anthraconauta* cf. *phillipsi*" is of doubtful

validity. The F Seam of Betteshanger (Kent No. 6 of Dines' 1945 classification = Millyard of Tilmanstone) carries "*Estheria*"[1] in its *phillipsii-pringlei* fauna and lies in the same belt of strata which, as shown in Text-fig. 2, yields "*Estheria*" elsewhere.

It appears, therefore, to be likely that the Lower or Shale Division which forms the lowest 700 feet of the Kent Coalfield includes a thin development of the Communis Zone, while the main portion of the upper part of the group should be referred to the Similis-Pulchra Zone. In view of the almost complete absence of *Anthracosia* perhaps it is the upper rather than the lower part of the Similis-Pulchra Zone which is indicated (see also pp. 276–7). It has to be remembered, however, that *Anthracosia* is rare in the Lower Similis-Pulchra Zone both in the Bristol Coalfield and in some areas in northern France. The faunas at present available are therefore inadequate to give a more definite correlation.

The Tilmanstone Marine Beds

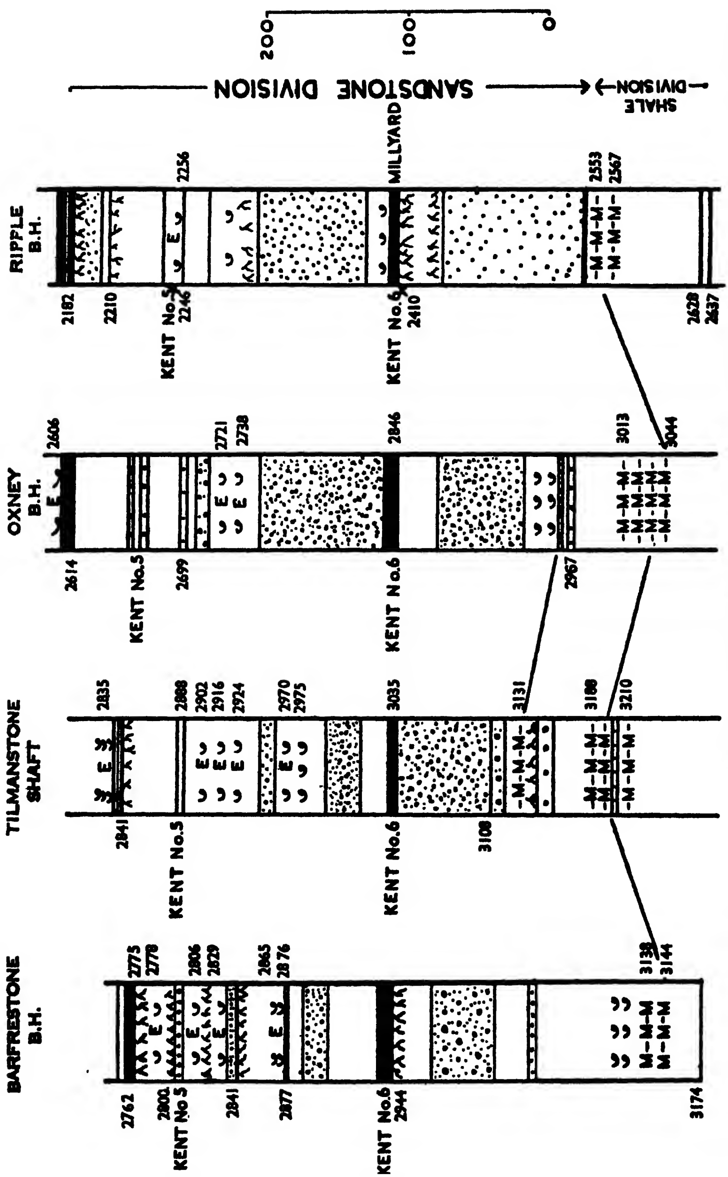
Some confirmation of the correctness of the correlation of the Kent No. 6 Seam, as also of the marine strata 130–190 feet below it, in several of the boreholes in the centre and south-eastern part of the Kent Coalfield is given in Text-fig. 3. The records of fossils from the Barfrestone, Oxney, and Ripple Boreholes are taken from Bolton's 1913 manuscript referred to previously, and it is to be noticed that the belt of strata 100 to 200 feet above the Kent No. 6 Seam (Millyard) in each case yielded "*Estheria*" associated with non-marine lamellibranchs. The Tilmanstone determinations were published in 1933 (Stubblefield) and included *E.* (*Euestheria*) *simoni* Pruvost and *E.* (*Estheriella*) *reumauxi* Pruvost, species which at Bruay in the Pas de Calais occur some 600 metres (nearly 2,000 feet) above the Rimbert Marine Band. The higher of the two marine bands at Tilmanstone Colliery (at 3,131 feet below surface) overlies a fireclay and appears to correspond with the cycle of sedimentation commencing with a coal at 2,967 feet at Oxney Borehole. At Oxney, however, non-marine strata appear to succeed the coal. At Chislet only one marine band has been located where it has been found in two underground boreholes and in a cross-measure drift at distances varying from 130 to 140 feet above Chislet No. 5 Seam (= Kent No. 9 Seam).

The non-marine lamellibranch horizon lying approximately midway between this Chislet marine band and Kent No. 6 Seam (Text-fig. 2) may be the representative of the Oxney cycle of sedimentation containing the non-marine lamellibranch horizon above the coals at 2,996 and 2,967 feet and that containing the equivalent of the Upper Tilmanstone Marine Bed.

The marine bands recorded from Walmestone and Mattice Hill Boreholes are likely to be at one or other of these two Tilmanstone horizons.

The more complete evidence now available concerning the sequence

[1] The generic name *Estheria* Rueppell 1837 is an invalid homonym of *Estheria* Robineau-Desvoidy 1830, the generic name of a Dipteran in current usage by entomologists. The name *Cyzicus* Audouin 1837 is used by zoologists for some of the living crustaceans formerly referred to *Estheria*, others are referred to *Leptestheria*. It is not clear, however, whether Carboniferous species are congeneric with either of these living forms ; until this is clarified it is expedient to refer to the fossils as "*Estheria*".



TEXT-FIG. 3.—Comparative Sections of parts of the Coal Measure sequence at various localities to illustrate the sequence for approximately 400 feet above the Lower Tilmanstone Marine Band. Depths in feet are given from surface. The symbols utilized are explained in Text-fig. 2 except for the conventional seat-earth symbol.

of non-marine shells in Kent makes it clear that the Tilmanstone Marine Beds may lie within or near the upper limit of the Similis-Pulchra Zone. It follows that the Tilmanstone Marine Beds may be the equivalent of one of the well-known marine bands in the upper part of that zone, namely the Cefn Coed-Mansfield horizon or the Cwmgorse beds: as two marine bands near this level are recorded at Tilmanstone it is remotely possible that both these South Wales horizons may be represented in Kent, but it has to be remembered that the Cwmgorse Marine Beds in their typical development give evidence of several distinct marine incursions, and also that less important marine bands frequently occur at short distances above and below the Cefn Coed or Mansfield Band. In northern France and in Belgium the marine band of Rimbert and the supposedly equivalent Petit-Buisson occur at an approximately similar level (there taken as the base of the Upper Similis-Pulchra Zone, since *Naiadites* extends for some hundreds of feet higher and *Anthraconauta* does not occur in force until a still higher horizon, Trueman, 1946, p. lxxv). In view of the proximity of the Kent Coalfield to the Pas de Calais it would at once be suspected that the Tilmanstone Marine Beds are equivalent to the Rimbert and Petit Buisson: in this connection it may be noted that the Rimbert in Hainaut (France) is usually represented by two marine beds, 18 to 20 metres apart (Renier, 1937): it is not recorded, however, whether there are intervening coals or seat-earths.

Turning next to the marine fossils themselves, the fauna of the Upper Tilmanstone Marine Band is known only from the Tilmanstone Colliery Borehole. As revised it comprises, *Lingula mytiloides* J. Sowerby, *Productus* ("*Pustula*") *rimberti* Waterlot, *P.* (*Dictyoclostus*) sp., cf. *Anthraconeilo taffiana* Girty, Orthocone nautiloid, *Anthracoceras ?*

The fauna recently collected from the marine shales at Chislet Colliery, which are known to be three or four feet thick, includes:—*Serpulites* sp., Athyrid ?, *Chonetes hardrensis* mut. θ (Hind),* *C.* (*Lissochonetes*) *minutus* Demanet,* *C.* (*Plicochonetes ?*) sp., *Crurithyris ?*, *Lingula mytiloides*,* *Lingula* sp. (finely ornamented and with a median ridge in the shell), *Orbiculoidea* cf. *nitida* (Phillips),* *Productus* cf. *carbonarius* de Koninck,* *P.* ("*P.*") *rimberti*,* *Trigonoglossa* [*Lingula*] cf. *nebraskensis* (Meek and Worthen), *Aviculopecten ?*,* *Anthraconeilo ?*, *Grammatodon ?*, *Nuculana* cf. *attenuata* (Fleming), *Bucaniopsis* cf. *tenuis* Weir, *Hollinella* cf. *bassleri* (Knight),* cf. "*Cypridina phillipsi*" Corsin.* The names followed by an asterisk denote that this or a closely allied form occurred at Tilmanstone in the Lower Tilmanstone Marine Band with which this Chislet marine horizon is now correlated (Text-fig. 2).

At Tilmanstone this lower marine band, which is 22 feet in thickness, contains carbonate bands at two levels (3,191 feet and 3,198–3,200 feet) and has yielded in addition to the fossils asterisked in the Chislet list—Crinoid stem columnals, *Martinia ?*, *Orthotetes ?*, *Phricodothyris* sp.,[1]

[1] When this form was first discovered in Kent, the hope was expressed, in 1933, that it might prove useful in future correlation work; in the intervening time I have examined many collections from marine bands in various British coalfields and the memoirs by Corsin and Demanet have been published on the French and Belgian marine bands. I have seen but one fragment and that

Productus (*Dictyoclostus*) cf. *americanus* Dunbar and Condra, *P.* (*Eomarginifera*) cf. *longispinus* J. Sowerby, *P.* (*Linoproductus*) cf. *tortilus* M'Coy (this form compares with the figure given by Demanet, 1943, pl. ii, fig. 19, named cf. *Productus* (*Linoproductus*) *cora* d'Orbigny, from the Petit Buisson Marine Bed), *Nucula* cf. *gibbosa* Fleming, *N.* cf. *wewokana* Girty, *Nuculana* cf. *acuta* (J. de C. Sowerby), *Palaeoneilo* sp., *Pseudamusium* or *Pernopecten*, *Platyconcha* sp., *Strobeus ?*, *Coleolus carbonarius flenuensis* Demanet, *Anthracoceras* sp., Orthocone nautiloid, *Temnocheilus ?*, *Rhabdoderma* sp.

The forms figured by Bolton from Oxney Borehole as *Productus scabriculus* (1915, pl. ix, figs. 23 and 28) are probably identical specifically with those figured by Waterlot (1933) and Corsin (1932) as *P.* ("*Pustula*") *rimberti*. This species, like *P.* ("*Pustula*") *piscariae* Waterlot, is not a true *Pustula*, nor does it seem to be a *Buxtonia* for the cardinal process appears to have two sub-parallel posterior prolongations which enclose the median septum. The two species should probably be assigned to a new genus. *P. rimberti* was originally described from the Rimbert Marine Band of north-west France. Lately it has been recorded from the Petit Buisson of south-west Belgium in the neighbourhood of Mons (Demanet, 1943); it is now known from Britain in the highest observed marine bands in the following coalfields :—the Nuneaton Marine Band of Warwickshire (Mitchell and Stubblefield, 1942), the Chance Pennystone of Coalbrookdale, the Forest of Wyre, and perhaps Flintshire; specimens from these coalfields are preserved in the Geological Survey collections. These marine bands are usually considered to be of the same general age as the Mansfield-Dukinfield-Gin Mine-Cefn Coed horizon, though in no case has the Upper Similis-Pulchra Zone non-marine lamellibranch fauna been found above them. It is also remarkable that there is evidence in each of the coalfields mentioned, except Kent and perhaps the Flintshire coalfield, that *P. piscariae*, of the earlier French marine bands, is a characteristic Productid of the Modiolaris Zone Marine Band (Stubblefield, 1941). The two species furthermore are unrecorded from marine bands in the Modiolaris and Similis-Pulchra Zones in other British coalfields.

Lissochonetes minutus, however, has not an entirely similar distribution for it is known from the Petit Buisson Marine Band in the neighbourhood of Mons, from Kent, from Warwickshire (Nuneaton Marine Band), Nottinghamshire (Mansfield Marine Band), Gloucestershire (Croft's End and Lower Winterbourne Marine Bands) and South Wales (Cefn Coed Marine Band). Were it established that either the Chonetid or Productid species were very short-ranged, it would be justifiable to affirm that the Lower Tilmanstone Marine Band was contemporaneous with the Nuneaton, Mansfield, Rimbert, and Cefn Coed Marine Bands,[1] but the evidence available does not yet warrant such a definite conclusion.

from the Mansfield Marine Band at Calverton Lodge Borehole in the southern part of the Nottinghamshire and Derbyshire Coalfield. The continental memoirs make no reference to any French or Belgian Coal Measure occurrence. This rarity may be due to a tendency for the genus to be restricted to an occurrence in carbonate rocks in Coal Measure times. C. J. S.

[1] From other considerations H. A. Baker (1935) concluded that the Tilmanstone Marine Beds are to be correlated with the Mansfield Marine Band.

The known horizontal distribution of these particular species probably reflects some feature in the conditions of deposition. Their absence from the more northerly coalfields may have been related to the occurrence in the south of a marine faunal province which had limited connections with the north in late Ammanian (" Middle Coal Measures ") times (Stubblefield, 1941). In the northern areas the marine faunas had a slightly different faunal composition from those in the south at the time of deposition of the Mansfield-Cefn Coed band (a distinction which was still more marked at the time of deposition of the Cwmgorse beds).

In view of these uncertainties in interpreting the evidence of the marine faunas as a basis of correlation of the marine bands, it is unfortunate that the non-marine faunas indicate little more than that the Tilmanstone Marine Beds probably lie within the Similis-Pulchra Zone. The Kent sequence, though incompletely known, suggests that the Tilmanstone Marine Beds may be near the upper limit of the Similis-Pulchra Zone, for fossils indicating a horizon not later than the Phillipsii Zone (*Anthraconauta phillipsii* and *Estheriella reumauxi* without *A. tenuis*) are found at no great distance above them, with forms near *A. tenuis* a little higher. *Naiadites* has not been seen above the Kent marine bands. The lamellibranch sequence near these horizons in Northern France and Belgium is not very fully known, but from the available evidence it does appear that the Rimbert-Petit Buisson marine bands lie within the Similis-Pulchra Zone, and not near its upper limit. Thus as we have noted, at some localities in France, *Naiadites* extends for some distance above the Rimbert horizon (Pruvost, 1937, p. 199).[1]

On the one hand, therefore, there seems to be some justification for considering the Tilmanstone Marine Beds as approximately equivalent to the Cwmgorse Beds, at the top of the Similis-Pulchra Zone, while on the other there are some species in the fauna which are unknown in the Cwmgorse and its equivalents but which would give support to correlation with the Mansfield-Cefn Coed horizon. The first alternative would apparently involve the rather surprising conclusion that the Tilmanstone Marine Beds (the only well established marine horizon in Kent) are at a diffierent horizon from that of the Rimbert-Petit Buisson of France and Belgium. A solution of the difficulty which must be borne in mind lies in the possibility that there is in Kent a break in the sequence leading to the omission of the Phillipsii Zone (or its lower part) and the uppermost strata of the Similis-Pulchra Zone. The apparently early entry of *Estheriella reumauxi* and *Anthraconauta tenuis* may be due to such a gap or to a great reduction in thickness of the Phillipsii Zone. If there is a break in the sequence, the Tilmanstone Marine Beds, notwithstanding the occurrence of faunas suggesting the Tenuis Zone a short distance above them, may well represent the Mansfield-Cefn Coed and the Rimbert horizon, but until much more detailed information is available concerning the sequence of faunas and floras both in Kent and in the Pas de Calais, it would be unwise to claim precise correlation.

In conclusion, thanks are rendered to the authorities of the collieries

[1] It may be remarked in this connection, however, that *Naiadites* occurs in Yorkshire at 350 feet above the horizon which has been taken as the base of the Phillipsii Zone (Wray and Trueman, 1931, Table A).

for the facilities afforded to the Geological Survey in its examination of drifts and borehole cores, in particular to Mr. A. E. Sutton and Mr. F. H. Price of the Chislet Colliery, Ltd. All the fossils from Tilmanstone and most of those from Chislet which are referred to in this paper were collected by the late Andrew Templeman, while Dr. J. Weir has confirmed the identification of some of the non-marine shells.

Postscript

Since this paper was written, a seven-foot marine band, containing a fauna which included *Productus* ("*P.*") *rimberti* has been located by one of us (C. J. S.) 220 to 227 ft. below the Millyard (Kent No. 6) Seam at Snowdown Colliery; and from 39 ft. lower in the sequence *Anthraconaia* aff. *pruvosti* and cf. *Naiadites daviesi* Dix and Trueman have been collected in shales yielding plant remains. The marine shales were underlain by measures including several seat earths and at 273 ft. below the Millyard, Mr. J. Ineson found a single specimen of the brachiopod *Trigonoglossa* attached to a *Calamites* fragment in the planty roof shales of a thin coal. This genus is known in British Coal Measures only from the marine band at Chislet Colliery. It would seem likely, therefore, that the Upper Tilmanstone Marine Band has thickened westwards and that the Lower Tilmanstone Marine Band is almost absent at Snowdown; the alternative explanation correlating the higher band with the Lower Tilmanstone Band would mean postulating a new marine band in the coalfield.

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Review and Critique

LES DIFFÉRENCIATIONS CHEZ LES GASTÉROPODES CAPULIFORMES : ORGANISATION DES PLATYCERATIDAE. By GENEVIÈVE DELPEY. *Bulletin de la Société Géologique de France* (5), 9, pp. 251–266, 1940 (for 1939).

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DURING 1945 and 1946 British and American palaeontologists have been beginning to learn of work published on the continent of Europe just before and during the late war that interrupted all normal communication. To the specialist the work of other specialists in the same field, or in closely related fields, is of great interest. My own field of specialization is the Gastropoda of the Palaeozoic and my interests naturally include problems of gastropod phylogeny and taxonomy on which information derived from the close study of the Palaeozoic gastropoda is of the highest importance. Naturally, then, when I discovered that Doctor Geneviève Delpey, of Paris, who began her work shortly before the war with Mesozoic gastropoda, had not only turned her attention to Palaeozoic gastropods (Delpey, 1941), but had so early in her career essayed extensive discussions on gastropod origins, phylogenies, and classification (Delpey, 1940*a* and *b*), I hastened to secure her works and study them assiduously.

Since all phylogenies are hypothetical and none are capable of proof, and since well founded and well reasoned hypotheses are valuable and welcome, it behoves one to be tolerant in criticism of a new one. But one expects any hypothesis to be based ultimately on more or less well substantiated facts and no hypothesis that is based on those that are erroneous and misinterpreted is worthy of further consideration. It is my contention that Delpey's hypotheses are based ultimately on misinformation as to the nature and relationships of certain Cambrian gastropod-like forms, erroneously regarded by her as Platyceratidae, and on inferences as to the morphology of those forms derived from false homologies between them and the Platyceratidae and between the Platyceratidae and the pleurotomarians.

Delpey's ideas as to the origin, taxonomy, and classification of the gastropods are set forth in two papers. In the first of these (Delpey, 1940*a*) she establishes the background for her hypotheses and this paper is fundamental. In the second (Delpey, 1940*b*) we find an elaboration and extension of her ideas under control of Bather's proposal of classification by " grades of organization " rather than by phylogeny. I shall comment briefly on the first of these papers.

Before discussing her paper a few comments of a general nature appear to be in order. It is important to recognize the fact that few French palaeontologists have had opportunities for an extensive acquaintance with pre-Devonian faunas from first-hand knowledge, for these faunas are poorly represented in France and her colonies, both in the field and in museums. Especially is this true in respect to Cambrian faunas. In addition it must be recognized that reports on Cambrian gastropods are largely the work of palaeontologists, most of them American, whose

field of special competence was of necessity trilobites. Consequently when a gastropod, or gastropod-like form, was met with it was assigned usually to some genus recognized in younger strata to which it was thought to have a superficial resemblance. Hence, since the gastropods of the Cambrian have never been revised in any comprehensive way, some of those very haphazard generic assignments remain in the literature to the confusion of those who, like Delpey, have had little or no first-hand contact with the specimens. This has been a fertile source of error to neontologists and palaeontologists unfamiliar with the circumstances. If there is any blame involved it cannot be laid at the door of French palaeontology. It must be placed chiefly at the door of American palaeontology, for the opportunities to correct the situation lie chiefly in America.

Since I cannot refer to published material for support for some of the views I will express on Cambrian gastropods and since time will not permit extensive revisionary treatment, I must perforce speak *ex cathedra* on the basis of considerable first-hand experience with American collections. On this basis I venture to assert that neither *Platyceras* nor any close relative of *Platyceras* has been found in Cambrian rocks. Likewise there is no *Straparolus*, *Straparollina*, *Euomphalus*, or *Raphistoma* or any close relatives of these, even though each of them is reported by some Cambrian worker. I have examined specimens of many of the species so referred, including some of the types, and in each case the affinities are with that puzzling group of gastropod-like forms that may be referred to as *Pelagiella* and its allies. For example, *Platyceras primaevum* Billings 1871, which is specifically mentioned by Delpey (1940*a*, p. 253) erroneously as of Walcott, is correctly referred to the genus *Pelagiella* Mathew 1895. *Pelagiella* includes as subjective synonyms *Parapelagiella*, *Protoscaevogyra*, and *Proeccyliopterus*, all of Kobayashi 1939, and all based, I think, on a misunderstanding of the characters of *Pelagiella* itself. The pelagiellid genus that most resembles *Platyceras* is *Semicircularea* Lochman, in Lochman and Duncan, 1944. So far from being obviously related to the *Platyceratidae* is *Pelagiella* that Wenz (1938, p. 95) expresses grave doubts that it is even a gastropod and, for reasons that will be set forth in another paper, I am inclined to harbour the same doubts.

Returning to Delpey's paper on the Platyceratidae, she derives fundamental data and assumptions from two prior sources ; Bouvier and Fisher, and Cossmann. From Bouvier and Fisher (1902, p. 240) she accepts the suggestion that the two branchial ganglia of *Pleurotomaria* are very large because they represent the fusion of the ganglia situated at the bases of the numerous gills of the supposedly ancestral Chitons, or preferably of the unknown form ancestral to both *Pleurotomaria* and the Chitons. This ancestor is therefore inferred to have been holobranchiate, that is to say, like the Chitons, it is supposed to have had numerous pairs of gills. This is, of course, quite a legitimate piece of speculation on the part of Bouvier and Fischer, but one that is not necessary to establish relationships with the Chitons and not strongly supported by other evidence.

Next Delpey accepts Cossmann's doctrine that the helicoidal shell of the typical and more advanced gastropods was derived from the Cambrian

"Capulidae" by the gradual assumption of coiling (Cossmann, 1915, p. 7). She recognizes, as Cossmann and his contemporaries did not, that there are no Capulidae in the Palaeozoic, and substitutes "capuliformes" for the Capulidae of Cossmann's doctrine. Adding together the speculation of Bouvier and Fischer that the ancestral gastropod was holobranch, the doctrine of Cossmann that Cambrian "Capulidae" ("Capuliformes" of Delpey) were primitive, and her own interpretation of the meaning of the sinuses of the lip of certain Platyceratidae (capuliformes) which will be discussed below, we have her picture of the origin of the gastropods from holobranchiate Cambrian Platyceratidae.

It is her interpretation of the platyceratid lip to which I must take particular exception. As has been known ever since specimens were collected, the lip in *Platyceras* and its allies is very irregular; that is to say, the margin is scalloped by several or many re-entrants, objectively sinuses, and intervening salient areas. Now the living dibranchiate gastropods, pleurotomarians in the broad sense, have a single sinus, or its homologous slit, hole, or row of holes, and the two gills, true ctenidia, are found one on each side of the sinus, or its homologue. Delpey now examines specimens of *Platyceras* and especially of the closely related genus *Orthonychia* and jumps to the amazing conclusion that the many sinuses in its lip are each to be homologized with the single sinus or slit of the pleurotomarian and that each sinus had a gill on each side of it! Therefore *Orthonychia* was holobranchiate and the hypothesis of Bouvier and Fischer as to the holobranchiate condition of the primitive gastropod appeared to be verified. She carries her ideas still further and, since the sinuses and salients of the Platyceratidae occur irregularly not only from genus to genus, species to species, and individual to individual, but often in different ontogenetic stages of the same individual, she supposes that the number of gills was equally variable, even in different growth stages of the same individual (Delpey, 1940*a*, p. 260). Surely this is morphological plasticity with a vengeance!

But let us leave the realm of fantasy, and even when speculating, let us try to keep our feet on the solid ground of facts and of probable interpretation of facts. In the first place there are no true *Platyceratidae* known from rocks older than Silurian. *Platyceras* and *Orthonychia* put in their first appearance in the Silurian and *Orthonychia* does not become abundant until Devonian time. There are a number of other platycerid genera ranging from Silurian time at least through the Permian (and perhaps further), but unless the Ordovician genus *Dyeria* Ulrich, in Ulrich and Scofield 1897, is a platyceratid, I fail to recognize the family in the Ordovician and certainly not in the Cambrian. Nor do I know from what the Platyceratidae were derived. I have suggested that they may have been derived from a simple helicoidally coiled form like *Holopea* of the Ordovician (Knight, 1934, p. 146), but of course Delpey cannot accept so conservative an hypothesis, for to her the Platyceratidae are already in existence in Cambrian time and are primitive and holobranchiate. Can it be that she is confusing the Platyceratidae with the group that Wenz in 1938 (p. 85) refers to as the Tryblidiacea? This group is "capuliform" and is indeed represented in the earliest Cambrian and may or may not have been holobranch. But Delpey

hardly mentions this group and its members show no sinuses in the lip to act as an infallible guide to the number of gills !

The quality of being "capuliform" has no phylogenetic meaning. It may be primitive, as Wenz and others (including myself) believe it to be in the Tryblidiacea, or it may be secondarily derived, as an adaptation to a sedentary life, as it is in many wholly unrelated groups, including in all probability the Platyceratidae. The evidence that the Tryblidiacea are primitive rests on a number of morphological features not the least important of which are the symmetrically paired muscle scars (Wenz, 1938, p. 58). I expect to discuss them further elsewhere.

The evidence that the Platyceratidae are secondarily capuliform derives in part from their relatively late geological appearance (Ordovician ?, Silurian-Permian) amply confirmed by their adaptation to a highly specialized sedentary life. The genera *Platyceras* and *Orthonychia* are not only sedentary but practically stationary throughout life. They are narrowly specialized for a coprophagous existence, fixed on the calyx of a crinoid, and there is nothing primitive about them. This is well known to workers in both Palaeozoic gastropods and crinoids and has been the subject of a number of papers by Charles R. Keyes, the definitive paper (Keyes, 1889), well known to Delpey and cited by her, being an unusually well-documented and well-reasoned piece of palaeozoological research. Amongst other things, it is well known that the shell-margin of the platyceratid is so perfectly fitted to the irregularities of the crinoid calyx that the position of the various irregularities of the shell margin, indeed, their very existence, is clearly under the control of the external factors, the irregularities of the crinoid calyx. Furthermore, there is no evidence whatever that currents carrying food and oxygen would tend to enter more readily at salients in the shell margin or that currents carrying away fouled water would escape through the re-entrants (sinuses) than at any other point, since because of the very close adjustment between shell margin and the irregularities of the crinoid calyx, the distances between shell and crinoid at the tips of either would be the same when the shell is lifted out of close contact with the crinoid.

Furthermore, since the platyceratid shell fixed itself over the crinoid anal opening (Keyes, 1889, p. 240) and since the full volume of anal ejecta of the crinoid therefore passed through the mantle cavity of the platyceratid, the currents must have been dominantly outgoing. Probably a small area under the anterior margin took in well oxygenated sea-water for the ctenidium, but the platyceratid probably was not dependent on such a current for food. There is no reason to believe that salients or re-entrants in the shell margin exercised any control over the localization of either incoming or outgoing current. And, likewise, there is no reason to homologize the re-entrants of the platyceratid margin sinuses (if one pleases to use only one's eyes and not one's intelligence) with the anal or efferent sinus, or slit, of the pleurotomarian.

That the platyceratid was coprophagous does not, of course, exclude the possibility that it may have supplemented that diet, as Delpey suggests, after the fashion of the living Capulidae. But the Capulidae are monobranchs. Finally, there is no reason whatever to suppose that the platyceratids were holobranch, and good reason on theoretical grounds

(probable derivation from monobranch ancestors) to suppose that they were monobranch.

If, then, my somewhat dogmatic statements are accepted that there were no certain Platyceratidae in the Ordovician and none whatever in the Cambrian, and if there is no valid reason to suppose that the Platyceratidae were holobranch in any case, there is little left of Delpey's hypotheses. In fact we stand just about where we stood before she wrote, with an interesting but unsupported hypothesis by Bouvier and Fischer that the primitive ancestor of the chitons and *Pleurotomaria* was holobranch. One need not think that the status of Cossmann's doctrine involving the " Capulidae " has been affected one way or another. It has never at any time attained any serious acceptance.

If in Delpey's work one may read " Tryblidiacea " instead of " Platyceratidae ", there might be some reason to consider it further. But then the inferences she draws from the scalloped margin of *Orthonychia*, one of the principal props for her hypothesis, would be irrelevant.

Finally, Delpey (1940*a*, p. 263) discusses the proposed classification of the Gastropoda into artificial groups by " Grades of Organization " that she had proposed in a previous work (Delpey, 1939, p. 19) and which she elaborates further in another (Delpey, 1940*b*). Since the basis of such a classification has always seemed to me unsound philosophically, and since the classification has no practical value, I have even less sympathy with Delpey's effort to employ it for the Gastropoda than I did with that of its originator, the late F. A. Bather, for the crinoids. Actually the so-called classification is hardly of greater value than the highest category of an artificial key based arbitrarily on the direction of the gastropod growth lines and not elaborated into lower categories. At any rate, her classification on this basis plays a small part in the work under consideration and I shall not discuss it further here.

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Persia. A Review of Some Recent Geological Literature.

By G. M. Lees.

1. Furon, R. Géologie du Plateau Iranien (Perse-Afghanistan-Béloutchistan). *Mém. du Mus. Nat. d'Hist. Naturelle.* Tome VII, Fasc. 2. Paris, 1941.
2. Schroeder, J. W. Essai sur la structure de l'Iran. *Eclogae geol. Helvetiae*, vol. 37, No. 1, pp. 37–81, 1944.
3. Hirschi, H. Über Persiens Salzstöcke. *Schweiz. min. und pet. Mitt.*, Bd. xxiv, Heft. 1-2, pp. 30–57, 1944.
4. Bonnard, E. G. Contribution à la connaissance géologique du Nord-Est de l'Iran (Environs de Méched). *Eclogae geol. Helvetiae*, vol. 37, No. 2, pp. 331–354, 1945.

The four works noticed above, published during the war years, are important contributions to our geological knowledge of Persia, and are also important stimulants towards tectonic controversy. Furon's position on the staff of the University of Tehran has given him an opportunity of extensive travel in Central and Northern Persia in 1923, 1924, 1936, and 1937, and he has assembled his own personal observations into a monograph incorporating also a digest of all published geological knowledge of Persia available to him, though unfortunately war-time circumstances seem to have prevented him from having access to the important work on Eastern Iran by F. G. Clapp, published in 1940 (*Bull. Geol. Soc. of America*, vol. 51, No. 1). Schroeder conducted a mining survey from 1939 to 1942, principally in the regions of Qum, Kirman, and Bandar Abbas, but his more limited experience has not interfered with the broadness of his brush used to paint in his structural speculations. Hirschi's observations on salt domes were made during the course of journeys in 1939 and 1940, and Bonnard was also engaged in mining prospecting, and spent the summer of 1940 in the province of Khorassan.

1. Furon has done an outstanding service to geology in assembling into one monograph an immense amount of information on Persia spread through scattered literature. Stratigraphy occupies about three-quarters of his book, with an excellent bibliography as its introduction. The remaining part discusses the palaeogeographical deductions from the author's compilation of facts and personal observations, and naturally a considerable speculative factor is involved. Furon discovered some structural elements in Central Persia in the Massif de Tabass with a pronounced north–south strike direction, and he regards this as evidence of a southward continuation of the Ural Hercynian mountain system. On palaeogeographical grounds he argues that this system continued southward through Oman, the Indian Ocean, and Madagascar, and he has named it the " Axe ouralo-irano-malgache ".

The Ural orogen in Russia disappears southward beneath a cover of younger rocks, and its further course is one of the unsolved problems of structural geology. The generally accepted belief is that it swings south-eastwards then eastward into the Tianshan mountains, but Furon's hypothesis is an attractive alternative. The strange southerly swing of the Oman ranges with a structural age (Upper Cretaceous) so different

from that of the outermost zone of the Persian folded belt indicates some pre-existing cause which might indeed be the influence of a Hercynian folded zone. Unfortunately, direct evidence in support of such an explanation is lacking, and the few exposures of Palaeozoic strata in South Persia tell a contrary tale. In the Gakum and Furgun mountains, north of Bandar Abbas, there are exposures in single scarp faces of the whole stratigraphical sequence from Ordovician to Cretaceous, and although there may be gaps in the succession (Devonian, for example, has not been identified palaeontologically), there is no detectable angular discordance. At these two localities, therefore, all was quiet on the Hercynian front. In Eastern Persia F. G. Clapp has mapped and described some north–south structural lines in the Afghanistan border zone near Zahidan, but in this case only Cretaceous and Tertiary rocks are exposed. He examined the area of Tabass, but has not recorded any specific observations on Palaeozoic movements.

The evidence for a north–south Hercynian fold system in Eastern Persia is, in my opinion, not sufficiently clear to justify the important deductions which Furon has drawn ; but he has done a service in drawing attention to the problem in such a provocative manner that it is to be hoped that he will stimulate further work on it. In 1928 I ventured some speculations on the nature of the Oman ranges [1] and suggested that the main fold-zone of pre-Maestrichtian age continued southward into the Indian Ocean in some such way as had already been suggested by Kober.[2] The alternative possibility is that the fold-arc swings eastward into the Arabian Sea, and eventually connects with the ranges of Baluchistan which run out to sea just west of Karachi. No further light has been thrown on this question during the subsequent years, and it remains an important problem awaiting solution. A gravity survey by a submarine in the Gulf of Oman and the Arabian Sea, using the technique of Vening Meinesz, should outline clearly the dominant strike directions, and so solve the question of the relation of Oman to India, and if it were extended sufficiently to the south it would show whether a continuous tectonic zone extends southwards towards Madagascar. The result would not necessarily support Furon's hypothesis of a continuous Hercynian orogeny, as the southward extension of Oman might arise from the early Alpine movements only.

Furon's monograph is accompanied by a coloured geological map of Persia and of the adjacent parts of Afghanistan and Baluchistan (scale 1 : 5,000,000) which unfortunately is not as good as it might have been. Admittedly it is difficult to generalize complicated geology on such a small-scale map, but in this case generalization has been so overdone as to give a wrong structural impression in some areas. For example, a 60 km. wide strip of Palaeozoic rocks has been shown along the entire length of the Zagros ranges, from the Turkish frontier to Baluchistan, whereas there are only some dozen exposures (excluding the abnormal salt plugs) of quite limited extent in the cores of major folds or fault slices. The dominant rock is the Middle and Lower Cretaceous limestones.

[1] Lees, G. M., *Quart. Journ. Geol. Soc.*, lxxxiv, 585–670, 1928.
[2] Kober, L., *Der Bau der Erde*, 1928, 276–7.

2. Schroeder has attempted a tectonic synthesis of Persia, presumably influenced in doing so by a recent synthesis of Anatolia by Arni. He shows on his map the following zones from north to south :—

1. Arrière-Pays.
2. Caucase.
3. Monts Turkmènes.
4. Elbourz.
5. Arménie Karabagh—Karadagh.
6. Iran central.
7. Urmiah—Dukhtar.
8. Iranides.
9. Plis Bordiers.
10. Socle arabe.
11. Arc alpine d'Oman.

These zones, which have a north-west-south-east strike direction, are crossed at right angles, according to the map, by ten " transversales soulevées " and " transversales deprimées ". The boldness of print suggests a degree of conviction which, in my opinion, is entirely unjustified. These transverse axes are shown to cross the mountain ranges without any structural features to justify them, except in the case of Oman, nor does the geological history as revealed by stratigraphy indicate such a pattern.

The geological structure of Central Persia is very difficult to analyse in simple terms. In the north the Elburz and in the south the Zagros mountain systems arise out of geosynclinal zones conforming to the general pattern, but the zone between is most complex. Sedimentation throughout Palaeozoic, Mesozoic, and Tertiary was spasmodic, and in general, though with many local exceptions, the thickness of strata was not great. Folding movements occurred in a number of phases, but without any simple pattern or uniform strike direction. H. de Böckh, F. D. S. Richardson, and I [1] suggested the term " median mass " to describe this element, and now both Schroeder and Bonnard criticize this term as a result of their experience. Richardson and I accept this criticism ; in fact, we have for some years been conscious that the term " median mass " is a misleading conception, indicating as it does a degree of resistance to deformation which Central Persia cannot claim.[2] The intensity of compression in many of the interior basins, for example between Qum and Tehran, where great thicknesses of Tertiary strata are involved, indicates considerable mobility. But if median mass is not correctly descriptive, Schroeder's alternative of " Iran central " is not descriptive at all of the structural character of the zone. Kober's term " Zwischengebirge " is probably a better term than " median mass ", as the compound term " Gebirge " indicates a complex without implying rigidity in the same way as does " mass ". The objection to " Zwischengebirge " raised by de Böckh was that it suggests a mountain complex, and so is not applicable to, for instance, the Pannonian Basin of Hungary or to the Caribbean Sea, but if the term is understood in its structural and not topographical sense, this objection can be waived.

3. Hirschi has described his personal observations on a number of the Persian Gulf salt domes and on those in Central Persia—Qum, Schurab, and Kuh-i-Gugird. Unfortunately for him during his work

[1] Gregory, J. W., *The Structure of Asia*, chap. iii, 1929.
[2] No political implication is intended.

and during the preparation of his paper he had been unaware that J. V. Harrison had already published an account of the Persian Gulf examples [1] giving a more complete regional review of the problem than was possible for Hirschi with his more limited experience. Hirschi discovered Harrison's paper, while his own was in the proof stage, and he was able to add a postscript in criticism of it. He finds it difficult to believe that the salt dome region is underlain by such thicknesses of strata, ranging in age from Silurian to Jurassic, as are exposed in the great scarps of the Gahkum-Furgun mountains because, otherwise, samples of these rocks would have been brought up here and there by the uprising salt masses, the salt being associated with rocks of Cambrian age. Consequently he regards the Furgun overthrust fold as belonging in reality to the thrust zone and not to the autochthon, but in my view this is most unlikely to be the case—Hirschi's objections notwithstanding. Our regional knowledge from surface exposures on the Persian side of the Gulf and from deep borings on the Arabian side all points to continuous sedimentation from Triassic, and probably from Permian, time onwards through Jurassic, Cretaceous, and early Tertiary.

The salt domes of Central Persia belong to an entirely different stratigraphic province, and Hirschi ascribes a Miocene age to the salt. In the case of the Qum salt occurrence he is in no doubt about the intrusive nature of the salt mass, but Furon (op. cit., p. 41) maintains that the salt occurs as a lenticle in its normal bedded position, and that it has not pierced its cover rocks. My personal observations strongly support Hirschi's opinion in this case.

4. Bonnard has presented the results of some detailed work in the vicinity of Meshed in North-Eastern Persia, and his paper is accompanied by a map on scale of 1: 100,000. He describes two prominent transgressions of Rhaetic and Middle Cretaceous ages, and gives the date of the intrusion of the granite mass as about Lower Cretaceous, as it has partially metamorphosed the Middle Jurassic sediments. He has distinguished two directions of movement—one N.W. to S.E., probably of Lower Cretaceous age, and the other W.S.W. to E.N.E. of an age previous to the Rhaetic transgression. The Middle Cretaceous transgresses over both of these fold systems with strong discordance.

The area surveyed by Bonnard lies in a zone of great structural interest, being the meeting point of the Elbourz and the Hindu Kush systems, and he discusses at length the importance of his observations. The tectonic generalizations of Suess, Argand, and Gregory were based on all too little exact knowledge of this part of Persia, and Bonnard's work shows clearly the necessity for much more detailed survey. The Palaeozoic structural history is almost completely unknown, and the importance of the Jurassic and Cretaceous phases of the Alpine movements in Central Persia is only gradually being realized. Bonnard criticizes the conception of " median mass " for reasons discussed above in the review of Schroeder's paper. He mentions Furon's assumption of a southerly extension of the Ural mountain system through Persia, but refrains from expressing a personal opinion.

[1] Harrison, J. V., The Geology of some Salt Plugs in Laristan (Southern Persia), *Quart. Journ, Geol. Soc.*, 86, 1930.

CORRESPONDENCE

CARBONATE PIPES AND RING STRUCTURES

SIR,—Mr. F. P. Mennell's interesting account in the *Geological Magazine* for May–June, 1946, of the Ring Structures with Carbonate Cores recently observed by him in Southern Rhodesia recalls certain closely comparable structures previously described from Southern Nyasaland,[1] the adjacent part of Portuguese East Africa,[1] South-West Africa,[1] and Uganda.[2, 3].

The Nyasaland complexes, described under the name of the Chilwa Series, are characterized by the presence of calcium carbonate pipes or vents ranging from a quarter of a mile to four miles in diameter, by alkaline and other intrusive plutonic rocks, including quartz-syenite, syenite, nepheline-syenite, ijolite, etc., and by swarms of dykes—sölvsbergite, tinguaite, nephelinite, and dolerite ; moreover, the limestone is intimately associated with a felspathic intrusive, essentially a high-potash orthoclase, and with masses of breccia or agglomerate containing angular and rounded fragments of felsitic and rhyolitic lavas and tuffs.

The Shawa and Dorowa ring structures described by Mr. Mennell resemble the Chilwa vents in the presence of the carbonate cores, the association with syenite, alkaline-syenite, ijolite, and other nepheline-bearing rocks, in the occurrence of masses of iron-ore, and in the wide range of petrographic types represented. They differ in that they include apatite rock, as well as serpentine and dunite (although peridotite occurs with one of the Chilwa dyke swarms), and in that they do not yet appear to contain agglomerates, manganese carbonates, fluorspar, and a wide range of minor intrusions. Moreover, while the carbonate of the Chilwa vents is normally a fairly pure limestone, that of the Southern Rhodesia cores is a dolomite. The Shawa and Dorowa occurrences resemble one of the eastern Uganda groups in the association of phosphate rock and of masses of magnetite with the carbonate cores. Certain of the Uganda centres, such as Napak, are associated with alkaline hypabyssal and agglomeratic rocks similar to those of Nyasaland.

The question of the age of these unusual complexes is of special interest, since the conditions of their formation seem to have recurred after one or more widely separated intervals. In eastern Uganda, for example, the igneous suites with associated carbonate rocks believed to be of direct magmatic origin form two distinct groups, between which a considerable age difference undoubtedly exists. The younger group is directly connected with a group of five volcanoes, namely Mts. Elgon, Kadam, Moroto, Napak, and Toror, which are believed to be of early

[1] F. Dixey, W. Campbell Smith, and C. B. Bisset : The Chilwa Series of Southern Nyasaland ; a group of alkaline and other intrusive and extrusive rocks and associated limestones. *Geol. Surv. Nyasaland Bull.*, No. 5, 1937.

[2] C. B. Bisset : Notes on the Volcanic Rocks of Central Karamoja. *Geol. Surv. Uganda, Bull.* 2, 1935, 41–3.

[3] B. C. King : Volcanic rocks of Napak area, Karamoja. *Geol. Surv. Uganda, Ann. Rep. for 1939*, p. 26. Also, Napak Area of Karamoja, *Uganda Geol. Surv. publication* (in the Press).

Pliocene age.[1] The Napak vent shows a central core about 1½ miles in diameter which intersects gneisses and schists of the Basement Complex, and in this central body a zone of carbonatites is completely encircled by ijolites. Residual sectors of the original volcanic cone, formed of agglomerates and lavas, show dips which are consistently outwards from the position of the core itself, and unmistakably reveal the relation of the core to the original cone, which was originally not less than 20 miles in diameter. This structure may be compared with that of the Nyasaland vents, which have been eroded far below the original surface level but still show hypabyssal rocks and abundant volcanic agglomerate in the carbonate cores, and with that of the Southern Rhodesia cores, which appear to have been eroded a stage further, so that only plutonic rocks are now seen in contact with the carbonate.

I understand from Dr. B. C. King, late of the Uganda Geological Survey, that the age of the older of the two Uganda groups is known only within wide limits, in that it intersects certain granites of Pre-Cambrian age, while it is in part overlain by extrusive rocks possibly related to the Elgon period of vulcanicity ; nonetheless, the stage of erosion reached by these Uganda vents prior to the early Tertiary is consistent with the view that they may be as old as Jurassic.

The Nyasaland vents were formed towards the end of the Stormberg volcanic episode, since they penetrate Karroo sediments and lavas and are overlain by the Lupata sediments believed to be of early Cretaceous age.

Mr. Mennell has considered the age of Shawa and Dorowa and indicates that on the meagre evidence yet available they may be of pre-Karroo age or may be referred to the Lupata volcanic outburst. They evidently have much in common with the late Karroo vents of Southern Nyasaland and Portuguese East Africa, and the stage of erosion reached by the Southern Rhodesia vents, whereby only plutonic rocks are now exposed, suggests that they are fully as old as those to the north. In this respect, and their association with apatite rock and with large masses of magnetite, they show greater resemblance to the older of the two Uganda groups.

If the ring-like, horseshoe-shaped, and arcuate outcrops of syenite, ijolite, and serpentine described by Mr. Mennell indicate separate intrusions in this form, as they appear to do, then they seem to represent a new feature in the African complexes of the Chilwa type ; for each of the latter normally comprises a group of separate intrusions in association with a vent or core, which sometimes shows a zonal arrangement of its constituents, but the intrusions themselves by no means form a ring-like or concentric pattern.

Such ring structures, as distinct from the carbonate cores, do, however, possess much in common, in plan at least, with the Younger Granite ring-complexes of Nigeria, which are being re-examined by the Geological Survey. Here the successive intrusions, which at Kudaru,[2] for example, include quartz-fayalite-porphyry and riebeckite-granite, form concentric

[1] K. A. Davies : The Age of Mount Elgon, and events in the Tertiary history of Bugishu. *Geol. Surv. Uganda, Ann. Rep.*, 1933, 69–71.

[2] A. D. N. Bain : The Younger Intrusive Rocks of the Kudaru Hills, Nigeria. *Quart. Journ. Geol. Soc.*, xc, 1934, 201–234.

ring-shaped and arcuate outcrops picked out in strong relief. They are, however, believed to be associated with circular fracturing, and in this respect they may differ from the Southern Rhodesia occurrences, which are also different petrologically. Nothing is as yet known as to the age of the Nigerian ring-complexes other than that they are post-Basement complex and pre-Cretaceous, but there are grounds for believing that their age is much nearer Cretaceous than pre-Cambrian.

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24th September, 1946.

CRYSTALLIZATION OF PLUTONIC AND HYPABYSSAL ROCKS

SIR,—In his paper on " The order of Crystallization of the Minerals in some Caledonian Plutonic and Hypabyssal Rocks " (*Geol. Mag.*, 83, pp. 206–216), Dr. Nockolds justly remarks that " the determination of the true order of crystallization of minerals in a plutonic intrusion is not an easy matter ". It would have been helpful, however, towards forming an estimate of his findings had he referred to the criteria actually adopted in his research. The following observations may nevertheless be made on his conclusions whatever the criteria used.

1. Contrary to Dr. Nockolds's statement on p. 209, discontinuous reaction can occur in a " eutectic system ", and will take place if the liquid-solid equilibrium curve, or surface, has a concealed maximum.

2. The only explanation for the successive cessations of crystallization amongst the ferromagnesian minerals (diagram, p. 209), is the assumption of a reaction-series : olivine → rhombic pyroxene → augite → hornblende → biotite. Augite is the only bridge between the crystallization periods of rhombic pyroxene and hornblende, and yet it is stated (p. 209) that rhombic pyroxene and augite " crystallize out side by side during part of their range ". It would be interesting to know how Dr. Nockolds would show this on a phase diagram.

3. On p. 209, Dr. Nockolds states that " the ferromagnesian minerals . . . all cease to crystallize before the final stage of the crystallization history is reached ". No phase can cease to crystallize in a cooling system unless, by reaction with the liquid another phase takes its place. The other phases present are plagioclase, potash felspar, and quartz, crystallizing along with the last member of the ferromagnesian " reaction-series ", biotite (p. 209), so that the ferromagnesian minerals are clearly not replaced in this way. No explanation is advanced by Dr. Nockolds of the remarkable cessation of crystallization of these minerals before the eutectic was reached.

4. Dr. Nockolds gives " the crystallization curve for the Caledonian igneous rocks " and states (p. 214) : " The crystallization curve constructed applies to the parental magma, the pyroxene-mica-diorite. If a liquid represented by any other point on the curve was separated from the earlier formed crystals, its curve of crystallization would follow a different course." The curve followed by the rocks thus shows the

crystallization of a liquid in contact with its deposited crystals. Dr. Nockolds's postulated plagioclase—potash felspar—quartz eutectic (p. 210), without iron and magnesium, is a physico-chemical impossibility for a liquid which started with these components.

5. Dr. Nockolds states (p. 214) that the crystallization curve determined by study of the rocks coincides with the theoretical curve followed by a liquid *in contact with its early crystals.* This evidence is conclusive that the postulated differentiation of various rock-types from a homogeneous magma, by *the separation of early crystals* from the liquid, did not take place.

6. Dealing with the pegmatites, Dr. Nockolds states (p. 216) that " it does not appear likely that they will fall on the ternary cotectic curve ". He explains this anomaly by pointing out their richness in volatile constituents " so that they no longer conform to laws applicable to more or less dry melts, like the aplites, but behave like watery solutions ". This reversion to the old physico-chemical fallacy of believing fusion and solution to conform to different laws is unfortunate.

7. On p. 214, Dr. Nockolds states that " differentiation took place in depth where a pyroxene-mica-diorite magma was undergoing progressive crystallization ". If the basic rocks were formed from this magma by the sinking of the early and heavy crystals, as appears to be the view of supporters of crystal-differentiation, the question why the basic rocks occur at the roofs of the Caledonian complexes arises. Does Dr. Nockolds continue to believe in " the intrusion of . . . crystals with little or no magma " ? (The Garabal Hill-Glen Fyne Igneous Complex. *Quart. Journ. Geol. Soc.*, 1940, xcvi, p. 505.)

8. What Dr. Nockolds's research shows is in fact that a magmatic interpretation of the Scottish Caledonian complexes cannot be reconciled with the firmly established principles of phase-rule chemistry. The present writer has examined the Loch Doon complex in Galloway using the principles and technique of phase petrology (as enunciated by Professor S. J. Shand) to test the rival magmatic and metasomatic hypotheses. The evidence found has led to the conclusion that the Caledonian complex of Loch Doon consists of rocks which have never been magmatic and which must be classified with the metamorphic rather than with the igneous rocks. The anomalies in the magmatic hypothesis, apparent as a result of Dr. Nockolds's investigation, suggest that the metasomatic type of genesis found to apply to the Loch Doon complex is likely to be the rule rather than the exception among the Scottish Caledonian plutonics.

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25th October, 1946.

AGE RELATIONS OF CERTAIN GRANITES AND MARSCOITE IN SKYE

SIR,—During his classic investigations in Central Skye towards the close of last century, Harker made several suggestive observations which, in the time at his disposal, could not be carried to a final conclusion. To this category belongs his statement, published in the *Geological Survey Memoir* in 1904 (p. 130), that in places the granites of the Red Hills showed interior intrusive contacts, and so had been built up by more than one act of intrusion. We have arrived at a more exact demonstration of this general conclusion during preliminary work for a comprehensive re-survey and petrological re-investigation of Central Skye.

In the north-western part of the Red Hills two distinctive granitic types have been recognized by us, namely, a biotite-hornblende-granite, and a rusty-weathering granophyric and slightly porphyritic type forming Beinn Dearg Mhor. These two types occupy extensive areas ; the Beinn Dearg Mhor type has a more central position and is chilled against the biotite-hornblende-granite, while the latter occupies peripheral and lower ground.

A third type occurring in this part of the Red Hills has been described by Harker as xenolithic (" spotted ") granophyre, and with this marscoite is intimately associated. Harker appears to have considered that marscoite occurred as distinct rock masses which were intruded into basalts, and some of his mapping supports this. He also considered that the acid magma which invaded the area was entirely later than the marscoite, and that it replaced much of the rock surrounding the marscoite intrusions, yet left marscoite sheets and dykes, considerably broken up and attacked by the acid magma, but still in roughly their original positions (see, for example, the *Skye Memoir*, pp. 188–191, and figs. 38 and 39). We have much to re-examine in the neighbourhood of Marsco itself, but elsewhere we have found contacts at widely separated points which show that marscoite and the associated xenolithic granophyre are later in age than the extensive mass of biotite-hornblende-granite mentioned above. On Sron a 'Bhealain, for instance, marscoite has been found in contact with the biotite-hornblende-granite at various places, and is in these cases clearly chilled against the granite, the latter, in contrast, not varying in grain size right up to the contact. Farther north, in the Allt Daraich and on Glamaig, marscoite presents similar, chilled edges against the biotite-hornblende-granite. At present we have no evidence of the time-relations between the marscoite with its associated xenolithic granophyre and the Beinn Dearg Mhor granite but this is probably to be obtained in the Marsco region.

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29th October, 1946.

TYPES OF ALLUVIAL DEPOSITS

SIR,—Dr. Challinor's article (*Geol. Mag.*, July–August, 1946) drawing attention to the laying down of two contrasted types of alluvial deposit—boulders and gravel in the bed of the stream with fine silts above—as a consequence of the normal processes of the activity of streams under certain conditions is welcome. Not only has this topic been inadequately handled in most text books, as pointed out by Challinor, but one even finds in Wooldridge and Morgan's well-known *Physical Basis of Geography* (1937) the statement (footnote, p. 171) that " generally speaking, the present valley floors of the world show alluvium overlying river gravel. This points to a general change in conditions . . . " *et seq.* My own view, which is identical with Challinor's, is stated in my *Physiography of Victoria* (1940), a copy of which is in the Library of the Geological Society of London (see pp. 55–58, Fig. 65). For the stream illustrated, I have observed both the movement of boulders with the river in spate and the deposition of silt during floods. While it is true that a change in the physiographic setting has occurred in many regions, leading to the deposition of silt in places where the streams were formerly transporting sand and gravel, the footnote above referred to requires considerable amplification if misconceptions are to be avoided in teaching.

The fault, if any, arises I think from a fairly general tendency in physiographic works to lay insufficient stress on the vagaries of " real " streams—variability of velocity and volume and its consequences—which are so significant for students such as engineers who may be called upon to cope with their effects.

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31st October, 1946.

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[R] indicates Review article